Kim Chwee Daniel Tan
Mijung Kim *Editors*

Issues and Challenges in Science Education Research

Moving Forward

Springer

Issues and Challenges in Science Education Research

Kim Chwee Daniel Tan • Mijung Kim
Editors

Issues and Challenges in Science Education Research

Moving Forward

Springer

Editors
Kim Chwee Daniel Tan
Natural Sciences and Science Education
National Institute of Education
Nanyang Technological University
Singapore

Mijung Kim
Curriculum and Instruction
University of Victoria
Victoria, BC, Canada

ISBN 978-94-007-3979-6 ISBN 978-94-007-3980-2 (eBook)
DOI 10.1007/978-94-007-3980-2
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2012938199

© Springer Science+Business Media B.V. 2012
This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.
The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.
While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

Contents

Chapter 1
Issues and Challenges in Science Education Research

Kim Chwee Daniel Tan and Mijung Kim

1.1 Science Education Research

In contemporary society, the rapid advances in science and technology, newly established societal and cultural norms and values, changes in the climate and environment, occurrences of natural and anthropogenic disasters, as well as the depletion of natural resources greatly impact the lives of people, their ways of viewing the world, experiencing phenomena around them, and interacting with others. Issues and challenges such as sustainable development, conservation and efficient use of energy and resources, the influence of ubiquitous information and communication technologies, and the ever greater impact of the developments in science and technology in daily life require science educators to rethink the epistemology and pedagogy employed in science lessons today.

Science is no longer a body of objective, value free, and separated knowledge from the challenging issues in the world. Knowledge is interdependent, collective, and emerging from dynamic interactions (Varela et al. 2000). In the reciprocal relationship between scientific knowledge and the world, teaching science is something more than an instructional activity to transmit content knowledge in the curriculum to students. It is an enactive action to interpret and build relationships between humans and the world through scientific knowledge and methods rather than locating scientific knowledge into an independent realm of cognition from the world. The question is how science education can help build a sound, sustainable relationship among knowledge, humans, and the life world.

K.C.D. Tan (✉)
Natural Sciences and Science Education, National Institute of Education,
Nanyang Technological University, Singapore
e-mail: daniel.tan@nie.edu.sg

M. Kim
Curriculum and Instruction, University of Victoria, Victoria, BC, Canada
e-mail: mjkim@uvic.ca

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_1,

Introducing the notion of science-in-the-making as opposed to ready-made science, Latour (1987) explains scientific knowledge as a process not a product. In ready-made science, knowledge is certain, fixed, and unquestionable truth, whereas in science-in-the-making, knowledge is open to challenges, contestable, and therefore tentative. Science as a process opens the possibilities of interactive and emerging scientific knowledge and the use of creativity in science work in our current society. The notion of science-in-the-making suggests the importance of questions in science education and research such as what and how to teach science in order to build better world to dwell in. The practice of science education needs to be proactive and relevant to the contexts that we live in today so that students are better prepared for the changes and challenges in the present and the future (Hodson 2003). To help students become critical thinkers and problem solvers, it is essential to nurture and support scientific habits of mind and inquiry skills, critical thinking skills and creativity, interdisciplinary investigations, and collaboration.

However, the level of science literacy is low in many countries, even in the industrialized nations (Miller 2004). School science abides in the domain of ready-made science rather than science-in-the-making, and students learn theories, laws, and formulae as the truth of the world out there (Kolsto 2001). Science teaching is still content oriented rather than context-bound. The effectiveness of teachers' practice is evaluated based on students' performance and assessment results. Given that traditional ways of understanding and teaching science, linearity of knowledge transmission, and content-based curriculum and assessment are no longer accepted as effective teaching and learning to address the complexity of problem solving in the lifeworld (Davis 2004), science education research is required to understand what and how to teach science in more effective and meaningful ways for students' lives and the whole society.

To bring forth the interdependent relationships among science, human and the society, science education research needs to pay more attention to the lifeworld contexts. It needs to produce insights to guide the teaching and learning of science in formal and informal contexts and to inform decision making on issues of science education (Millar et al. 2006; Treagust 1995) as well as teacher education; it needs to challenge practices which are ineffective as well as irrelevant in the present times, validate and support those which are sound and effectual, and appraise innovations to be implemented in the classrooms (Millar et al. 2006).

1.2 The Structure of the Book

With the concerns above in our mind, we address issues of scientific literacy, teacher knowledge and education, technologies in science teaching, and informal contexts of science education in this book. We highlight thought-provoking papers including the keynote lectures which were presented at the International Science Education Conference in November 2009 and which address the current issues and challenges in science education and science teacher education. The book is divided into four sections: learning and teaching of science, science teacher education, innovations and new technologies in science education, and science teaching in informal settings.

Part I concentrates on the learning and teaching of science. Larry Yore proposes Vision III of Science Literacy for All to provide a framework for the teaching and learning of science and science education research and reform. Scientific inquiry is an essential component of scientific literacy and Barbara Crawford discusses ways to support teachers to teach science as inquiry and help students to develop the essential skills required as well as learn science through inquiry and argumentation. Reinders Duit and David Treagust revisit conceptual change perspectives and argue that conceptual change, when multiple epistemological perspectives of teaching and learning are taken into account, is still a relevant and potent framework for instructional design and for improving students' learning of science. The learning of science requires students to be competent in the interpreting and using multiple representations, and how students demonstrate their understanding of organic chemistry through speech, inscriptions, and gestures is described by Shien Chue and Daniel Tan. To complete Part I, Helena Nas makes a case for alternative modes of assessment as her study shows that students are better able to demonstrate their understanding of photosynthesis and respiration in oral interviews compared to written tests, and Niwat Srisawasdi gives an example of the use of computer-based laboratory environments to support students engaging in authentic scientific investigations.

Science teacher education is the focus of Part II. This section discusses the development of teachers' pedagogical content knowledge and skills through sharing strategic models of teacher education program, teachers' challenges and dilemmas in assessment and inquiry, and the need to prepare teachers to teach science for sustainable development. Syh-Jong Jang proposes a peer-coaching model, PCK-COPR (PCK Comprehension, Observation, Practice, and Reflection), for enhancing the pedagogical content knowledge of preservice science teachers. Benny Yung discusses teacher professional development in the context of mandated school-based practical assessments, documenting the struggles of teachers with the issues of assessment requirements and student learning during practical work. This section continues with the accounts of teacher practices as well as interventions put in place to help teachers develop the knowledge and skills required for classroom teaching. A creative and cooperative science and technology teacher education course to foster problem solving and the development of novel pedagogies among teachers is described by Ossi Autio and Jari Lavonen, followed by Christine Howitt and colleagues who illustrate the challenges of helping preservice early childhood teachers acquire science content, pedagogical skills, and confidence to teach science to very young children through a collaborative approach. Mijung Kim, Yong Jae Joung, and Hye-Gyoung Yoon examine teachers' difficulties in science-inquiry teaching through rethinking the meanings of hypothesis and challenges of hypothesis construction test and data interpretation in elementary science classrooms. This section concludes with Kathryn Paige and David Lloyd introducing pedagogical strategies and practices to enhance preservice teachers' expertise and confidence to teach primary and middle-school science for sustainable development in the current society.

Part III discusses the use of innovations and new technologies in science teaching and learning. Susan Rodrigues describes research findings from a series of her previous research projects and summarize the opportunities and challenges of using multimedia-based simulations to support chemistry education. Karen Murcia discusses case studies on the impact of interactive whiteboard technology on science learning and teaching and teacher professional development. Yam San Chee and colleagues introduce the Legend of Alkhimia, a multiplayer computer game for the learning of chemistry, and discuss the epistemological and pedagogical bases of design-for-learning with computer games. Finally, Julie Crough, Louise Fogg, and Jenni Webber summarize the affordances of educational technologies and the barriers to adopting these technologies in schools in sparsely populated and remote areas where the infrastructures to support such technologies are inadequate.

Part IV presents science learning in informal settings, an increasingly important area of science education. Elaine Blake and Christine Howitt explore how very young children learn science in early learning centers and the importance of providing play time, resources, and adequate space as well as the role of a significant adult to facilitate the children's learning of science. Junqing Zhai examines how two botanic garden educators' pedagogical practices support visitors' learning of ecological science and proposes how such educators' professional development can be supported. Jennifer Yeo and Yew Jin Lee focus on knowledge building and describe students' learning of environmental science concepts during a nature learning camp.

We conclude this book with our articulation of and reflection on how research needs to impact practice and policy. We hope this book is taken as all the conference participants' collaborative efforts to question where we are now, as science educators and researchers, and where we need to venture in order to address the issues and needs of a changing world.

References

Davis, B. (2004). *Invention of teaching: A genealogy*. Mahwah/London: Lawrence Erlbaum Association Publishers.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*(6), 645–670.

Kolsto, S. (2001). Scientific literacy for citizenship: Tools for dealing with the science dimension of controversial socioscientific issues. *Science Education, 85*(3), 291–310.

Latour, B. (1987). *Science in action*. Cambridge: Harvard University Press.

Millar, R., Leach, J., Osborne, J., & Ratcliffe, M. (2006). Research and practice in education. In R. Millar, J. Leach, J. Osborne, & M. Ratcliffe (Eds.), *Improving subject teaching: Lessons from research in science education* (pp. 3–23). London: Routledge.

Miller, J. D. (2004). Public understanding of, and attitude toward, scientific research: What we know and what we need to know. *Public Understanding of Science, 13*, 273–294.

Treagust, D. F. (1995). Diagnostic assessment of students' science knowledge. In S. M. Glynn & R. Duit (Eds.), *Learning science in the schools: Research reforming practice* (pp. 327–346). Mahwah: Lawrence Erlbaum Associates.

Varela, F., Thompson, E., & Rosch, E. (2000). *The embodied mind: Cognitive science and human experience*. Cambridge: The MIT press.

Chapter 2
Science Literacy for All: More than a Slogan, Logo, or Rally Flag!

Larry D. Yore

2.1 Introduction

During the early years of my long career, educational research and instruction was dominated by B. F. Skinner's stimulus-response conditioning and behavioralist interpretation of learning, the distillation of complex events into simple sequential tasks, and skill-and-drill approaches to teaching. Language was restricted to one-way communication and knowledge transmission functions. Science education and language arts programs of this time reflected these influences with controlled vocabulary, decontextualized direct instruction, and programmed learning. Later, Jean Piaget's model of cognitive development, logico-mathematical operations, and developmentally appropriate, hands-on, learner-centered instruction dominated educational research and practice. Language and social transmission functions, although mentioned, were not fully considered. Science education and language instruction became experiential activity-oriented (discovery learning, whole language, etc.) leading to *activity mania* where researchers and teachers believed that when one activity does not result in understanding, you should provide additional activities. Direct teaching and explicit instruction in all contexts were bad words!

The current science education reforms in many countries, unlike the 1960s reforms based on a *Cold War* political agenda to produce more scientists and engineers, promote *Science Literacy for All*, constructivist teaching, and authentic assessment (Ford et al. 1997; Hand et al. 2001). Constructivist teaching and authentic assessment will be considered by other authors in this book (Duit 2012 (this book); Yung 2012 (this book)); therefore, I will not spend a great deal of time or space on

---

L.D. Yore (✉)
Department of Curriculum and Instruction, Faculty of Education,
University of Victoria, Victoria, BC, Canada
e-mail: lyore@uvic.ca

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_2,

these important ideas other than to paraphrase and elaborate the two most important ideas from cognitive psychology: First, find out what students know, challenge or use these ideas to facilitate their meaningful understandings. The centralist views of constructivism (interactive-constructivism, social constructivism) enacted as teaching approaches involve sociocognitive or sociocultural interpretations, group dynamics and negotiations, individual reflection and sense making, and a balance of self-directed and teacher-guided activities. Specific instruction choices are based on students' and teachers' ontological assumptions, epistemological beliefs, prior knowledge, concurrent sensory experiences, available information sources, and interactions within the learning environment. Language assumes a wider variety of representative modes (forms) and constructive, persuasive, and communicative roles (functions) in science inquiry and learning. Direct instruction and modeling are provided as *just-in-time* teaching on an *as-needed* basis and consider the metacognition necessary to facilitate students' explorations and learning. Second, assessment must reflect and be aligned with instruction and the target-learning outcomes to empower learning and inform instruction (assessment *for* learning) as well as to evaluate understanding (assessment *of* learning).

Over the last five decades, various science educators have advocated or critiqued science/scientific literacy that involved some form of economic, democratic, or social action rationale (Arons 1983; Bauer 1992; Bybee 1997; Coll and Taylor 2009; DeBoer 2000; Fensham 1985; Hurd 1958; Laugksch 2000; Linder et al. 2007; Miller 1983; Pella et al. 1966; Shamos 1995; Shen 1975)—but they all emphasized scientific knowledge, processes, or applications. Roberts (2007) developed a binary classification of these definitions (which did not emphasize the *literacy* component) of science/scientific literacy—Vision I is "rooted in the products and processes of science [while Vision II involves] the character of situations with a scientific component, situations that students are likely to encounter as citizens" (p. 730). Unfortunately, there is a real danger that the lack of a contemporary definition and shared understanding of *Science Literacy for All* will allow popularity of this slogan, logo, or rally flag to dissipate without realizing its full potential and worldwide cachet. McEneaney (2003) stated it has been "embraced worldwide as a worthy educational goal even though there is no consensus about what counts as scientific literacy" (p. 218), but she cautioned to avoid defining literacy as a "litany of facts known by literate individuals" (p. 230).

This lack of agreement has allowed diverse groups to agree about *science literacy* at the surface level since very few people would support *science illiteracy,* without really engaging the critical attributes and fine structure of this central and essential goal necessary to influence science education policies and practices! The diversity of these views and their goals will likely (a) reduce the creditability within the academic science and school-based education communities, (b) inaccurately reflect the nature of contemporary scientific enterprises, and (c) not provide a defensible foundation for school curricula and achievable goals for instruction. *Vision III of Scientific Literacy for All* proposed in this chapter is based on a sociocognitive framework, anchored in science education reforms, curricula, and schools, and reflective of the language in science research that integrates the nature of science, learning, language, and teaching. This interpretation provides theoretical and practical foundations on which to base future elementary and secondary school (kindergarten to grade 12 in North America—K-12) science education policies, reforms, and classroom practices.

2.2 Background

There is an emerging consensus within parts of the science (Alberts 2010; Hines et al. 2010), literacy education (Fang and Schleppegrell 2010; Moje 2007; Pearson et al. 2010), and science education (Carlsen 2007; Kelly 2007; Yore et al. 2003) communities about the need to focus on the literacy aspects of science literacy. This interpretation of science literacy (Vision III) is taken as being composed of two interacting clusters of cognitive, affective, communicative, and technological abilities related to science—fundamental sense of being a literate person in science—and knowledge of science and the scientific enterprise—derived sense of understandings flowing from human endeavors related to nature and naturally occurring events that allow for fuller participation and engagement of science in a social context. Here, science literacy is taken as a specific illustration of disciplinary literacy in which the literacy component is recognized and valued for its functional roles in constructing understanding, persuading others of the veracity of these ideas, and reporting knowledge claims (Fang 2005; Moje 2008). Shanahan and Shanahan (2008) outlined a developmental progression involving basic generic practices that elementary (K-3) school students should use across all texts, more sophisticated contextual practices that upper elementary and middle school students should use in certain textual situations, and technical and nongeneric practices that high school and university students should use with discipline-specific texts. Convergence of contemporary views of science, learning, and pedagogy has led to Vision III of scientific literacy. This vision emphasizes science as inquiry, argument, and constructing knowledge claims and explanations of patterns in nature and naturally occurring events; the essential constructive, persuasive, and communicative functions of languages in doing science; the unique conventions, traditions, and metalanguage in scientific discourse; and the functionality of language in teaching and learning science.

2.3 Disciplinary Literacy in Science Education Reforms

The Science Council of Canada conducted a deliberative inquiry involving diverse stakeholders during the 1979–1984 period that led to Report 36–*Science for Every Student: Educating Canadians for Tomorrow's World* (Science Council of Canada 1984). This report laid much of the foundation for an interpretation of scientific literacy focused on all students, underserved populations, authentic science and technology, and science-technology-society-environment (STSE) issues. Analyses

Table 2.1 Interacting senses of scientific literacy (Yore et al. 2007a, p. 568)

Fundamental sense	Derived sense
Cognitive and metacognitive abilities	Understanding the big ideas and unifying concepts of science
Critical thinking/plausible reasoning	Nature of science
Habits of mind	Scientific inquiry
Scientific language arts (reading, writing, speaking, listening, viewing, and representing in science)	Technological design
Information communication technologies (ICT)	Relationships among science, technology, society, and environment (STSE)

of current reform documents, standards, benchmarks, and learning outcomes from the USA (Ford et al. 1997), English-speaking countries (Hand et al. 2001), and Canada (Yore et al. 2007a) were used to articulate Vision III of scientific literacy that considers the interactive roles of language, learning, and understanding and started to elaborate the fundamental literacy cluster and the derived scientific understanding cluster anchored to the expectations of schools (Table 2.1).

Furthermore, the achievement of science literacy has a citizenship focus that leads to fuller participation in the public debate about STSE or socioscientific issues (SSI) leading to informed solutions and sustainable actions. Cross (1999) stated "it is recognized by all that this is only the beginning, and citizens will, one way or another, be involved in lifelong education if they are to participate in the ongoing debates about the changes occurring in society" (p. 699). The specific issues cannot be predicted for inclusion in long-lasting curricula; however, to remain literate about developments in the technocratic society, people will require critical knowledge, emotional dispositions, thinking ability, and literacy strategies.

Vision III integrates the cognitive, linguistic, pedagogical, and philosophical aspects of science and disciplinary literacy within a constructivist interpretation of learning and teaching in science. Many curricula do not explicitly mention science literacy, but they emphasize common features to the curricula analyzed above, which provide an implicit basis for using Vision III as the foundation for second-generation science reforms. The clusters and components in Table 2.1 vary in degrees of specificity, consistency, and clarity across curriculum documents in English-speaking countries; but this framework captures the material and social practices of scientists and disciplinary conventions and traditions embedded in the contemporary scientific enterprise (Ford 2008; Ford and Forman 2006).

The extant literatures in literacy education and science education are steadily increasing the clarity and evidential support for these clusters and in refining the characteristic of the entries in each cluster (Fang and Schleppegrell 2010; Holbrook and Rannikmae 2007; Pearson et al. 2010; Webb 2009, 2010). The science-understanding cluster is reasonably well defined by the curricular documents in each nation with some degree of agreement across jurisdictions; however, the specificity of the fundamental-literacy cluster is somewhat vague. This concern is being addressed by the rich and diverse research agenda related to science literacy, language arts in science, and public understanding of science reported in a number of special issues and reviews (Coll and Taylor 2009; Hand et al. 2006; Phillips and Norris 2009; Prain and Waldrip 2010; Yore et al. 2003, 2007a). Research literatures are also clarifying the mechanisms involved in the cognitive symbiosis within and between these clusters (diSessa 2004; Gunel et al. 2007; McDermott and Hand 2010; Snow 2010; van den Broek 2010). Exploratory talk, argument, transforming representations, writing-to-learn, and reading-to-learn instruction have distinctive effects on science understanding; metacognition and content and discourse understanding influence language performance in science.

The underlying backings for this vision of science literacy are found in the nature of science (ontological assumptions and epistemological beliefs) and the communicative, constructive, and persuasive functions of language for scientists doing and students learning science. Language is not only used to report understandings; it and the publication process (knowledge construction cycle) shape what is known and persuade others about the validity of these claims arising from discussion, negotiation, and argumentation.

2.4 Derived Sense of Scientific Literacy

The derived sense of scientific literacy illustrated in Table 2.1 is reasonably well understood and accepted in the science education community and international science education reform documents as understanding the critical principles and foundations of science (Hand et al. 2001). There is some disagreement on the specific ideas that would be considered critical and foundational as illustrated by the specifics identified in various reform documents, curriculum standards, and benchmarks. This 50-year-old ongoing debate is likely to continue, but at least it has progressed beyond a laundry list of trivia to a reasonable collection of big ideas (see *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* http://www7.nationalacademies.org/bose/Standards_Framework_Homepage.html), which taken at the general level, illustrate a reasonable degree of consensus.

2.4.1 Big Ideas and Unifying Concepts

The big ideas and unifying concepts are the major content for biological, earth and space, and physical sciences that apply across domains and topics or provide a foundational basis for work in a specific domain. A quick comparison of national standards, frameworks, or curricula that follow illustrates the variations in alignment among what is believed to be essential and foundational. The Science for All Americans: Project 2061 (American Association for the Advancement of Science [AAAS] 1990, 1993) identified these common themes: constancy and change, models, scale, and systems. The Pan-Canadian Framework for Science (Council of Ministers of Education 1997) identified these unifying concepts: constancy and change, energy, similarity and diversity, and systems and interactions. The US National Science Education Standards (NRC 1996) identified these unifying concepts: change, constancy, and measurement; evidence, models, and explanations; evolution and equilibrium; form and function; and systems, order, and organization. The lower secondary science curriculum (Singapore Ministry of Education 2010) identified these big ideas: diversity, cycles, energy, interactions, models and systems, and measurement. The framework for science education in the USA (NRC 2011) have proposed these crosscutting concepts, namely, cause and effect: mechanism and prediction; energy and matter: flows, cycles and conservation; form and function; patterns, similarity, and diversity; scale, proportion, and quantity; stability and change; and systems and system models.

2.4.2 Nature of Science

Science is frequently promoted in the science education reforms as inquiry, but it could equally well be defined as argument. Scientists use unique patterns of exploration to investigate defined problems and hypotheses and argumentation that attempt to establish clear connections among claims, data, backings, warrants, evidence, counterclaims, and rebuttals regarding those problems or hypotheses. Science is people's attempt to systematically search out, describe, and explain generalized patterns of events in the natural world and, also, that the explanations stress natural physical causalities and cause-effect mechanisms (Good et al. 1999). "Explanations about the natural world based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not science" (NRC 1996, p. 201). Science distinguishes itself from other epistemologies (ways of knowing) and from other bodies of knowledge through its metaphysics (ontology), the use of empirical standards, canons of evidence, logical arguments, plausible reasoning (abduction, induction, deduction, hypothetico-deduction), and skepticism to generate the best temporal explanations possible about reality.

2.4.3 Scientific Inquiry and Technological Design

Scientific inquiry is a creative, dynamic, and recursive process. There is no universal, lockstep scientific method. Authentic inquiry involves a cycle of false starts, unproductive moves, repeated trials, and revised procedures leading to knowledge claims and explanations. Technological design differs from scientific inquiry in its goal and procedures. Technology adapts the environment to people's needs, alleviates problems, or increases capacity (International Technology Education Association [ITEA] 2007; United States National Academy of Engineering [NAE] 2002). Therefore, technology is not just an applied use of known scientific ideas; sometimes, designs occur before the science is understood. Technological design values both tinkering and the trial-and-error approaches of the inventor. It involves identifying needs and opportunities, material and production limitations, generating designs, planning, making, testing, evaluating, and communicating. Interestingly, greater compatibility is found between technology and traditional knowledge than science and traditional knowledge across indigenous cultures (Yore 2008).

2.4.4 Relationships Among Science, Technology, Society, and Environment

"Science and technology are like conjoined twins. While they have separate identities, they must remain inextricably, connected in order to [flourish]" (ITEA 2007, p. 44). Furthermore, society influences science and technology, and science and technology influence society (STS issues). Less well understood is the influence science and technology have on the environment—the silent "*E*" in early interpretations of STS. Clearly, some of the most pressing and relevant issues facing people today involve various combinations of scientific, technological, and societal demands and influences on the environment. Climate change, population, clear-cut forestry, pollution, genetic modifications, and many other science discoveries and technical innovations are major concerns. "From a philosophical point of view, democratic principles imply that decisions affecting many people or the entire society should be made with as much public input as possible.… Increased citizen participation would add legitimacy to decisions about [science and] technology and make it more likely that the public would accept those decisions" (NAE 2002, p. 4).

2.5 Fundamental Sense of Scientific Literacy

The fundamental sense of being literate in a discipline involves the abilities to understand and communicate specific discourses associated with the discipline and then to construct understanding from those discourses for the purpose of fuller participation in the public debate (Moje 2008). Furthermore, fundamental literacy in a discipline is contextualized and plays an interactive role with the derived sense of literacy dealing with the knowledge of the domain. When these ideas are applied to scientific literacy, there is a cognitive symbiosis within and between the fundamental and derived senses with each stimulating and enabling growth in the other. Users of science discourse (oral or written) cannot fully comprehend the discourse without appropriate knowledge of the nature of science, scientific inquiry, and the content of science. A contemporary evaluativist, naïve realist view of science will influence and limit the language and metalanguage used; it differs from the discourse associated with an absolutist, realist or relativist, idealist views of science (evidence supports, not proves, tentative claims, not truths, etc.). Utilization of information communication technologies (ICT) will require development of a critical stance as a habit of mind and will likely change how learners make sense of multimodal electronic text, as compared to writing-reading and representing-interpreting with more traditional forms of text.

Scientists working on authentic inquiries and engineers working on authentic design problems and innovations demonstrate and use both well-developed fundamental and derived senses of scientific or technological literacy to create their insights and innovations. The fundamental sense of scientific literacy involves more than the ability to read and write discourse in the science domains and communities; it embellishes a variety of cognitive, thinking/reasoning, linguistic, and technical abilities and strategies (clusters of complementary skills directed at achieving the same outcome). These abilities and strategies deal with human learning and construction of understanding focused on doing, epistemological practices, and knowledge about and executive control of inquiry, design, problem solving, troubleshooting, and argumentation.

2.5.1 Cognitive and Metacognitive Abilities

The construction of scientific understanding involves a variety of ontological assumptions and epistemological principles that define the nature of science and how scientists go about doing science. The actions (verbs) applied correctly and effectively produce knowledge claims and explanations (nouns). These cognitive and metacognitive abilities and strategies include but are not limited to (Yore et al. 2007b):

- Making sense of the world and building and monitoring knowledge claims
- Critical analysis of claims, procedures, measurement errors, data, and so forth
- Justifying data as evidence for/against a claim based on the theoretical backings/warrants
- Planning, conducting, evaluating, problem solving, troubleshooting, and regulating inquiries and designs

2.5.2 Critical Thinking/Plausible Reasoning

Deciding what to believe or do about a challenge is central to most descriptions of critical thinking (Ford 1998). Scientific-literate people faced with a worthwhile challenge, issue, or problem deserving consideration will conduct appropriate deliberations of evidence, criteria, and opinions to make a judgment about what to do/believe and will openly justify the claim/judgment. Critical thinkers reflect on the deliberations as they are being done (reflection *in* action) and on the results of the deliberations (reflection *on* action). Furthermore, critical thinking from a metacognitive perspective can be viewed as thinking about your thinking as you are thinking to improve the quality of your thinking. Clearly, there appears to be a convergence of critical thinking, metacognition, and reflection (Ford and Yore 2012). Plausible reasoning (induction, deduction, abduction, hypothetico-deduction) within the scientific enterprise and the public consideration of scientific claims has regained a central emphasis in science learning, curricula, and teaching (NRC 2007).

2.5.3 Habits of Mind

Emotional dispositions (habits of mind) toward science inquiry and technological design reflect the nature of science and technology (AAAS 1993). These habits of mind (beliefs, values, attitudes, critical stance, processes, and skills) regarding science include dispositions, such as skepticism, tentativeness, certainty, trust, self-efficacy, willingness to seek solutions, buttress claims with evidence, evaluate data, information, reasons, and arguments; and view science and technology thoughtfully, being neither categorically antagonistic nor uncritical; openness to compare and consider trade-offs; and appreciate the roles of chance and errors in relationships (Yore et al. 2007b).

2.5.4 Scientific Language

Scientific-literate people speak-listen, write-read, and represent-interpret using natural and mathematical languages; follow directions; state a purpose for stepwise procedures; produce compelling arguments, sound explanations, clear descriptions, or mathematical expressions; and use the metalanguage of science in a proper and appropriate manner that reflects an accepted view of science. A synergy exists between science and language learning; purposeful integration of science, language, and rhetoric results in an understanding of both science and language beyond the scope of when either is used separately (Stoddart et al. 2002). Constructive/interpretative functions of language (talking-listening, writing-reading, representing-interpreting) are paired tasks that help users acquire information; compare, classify, and analyze ideas; persuade others; and construct understanding—language shapes as well as reports what we know. These functions mirror the science processes, cognitive procedures, and metacognitive strategies used by scientists *doing science*, cognizing and recognizing their understandings, and communicating and reporting these ideas to others, which are different from social language and cannot be assumed to develop without explicit support (Yore et al. 2006).

2.5.4.1 Talking-Listening in Science Literacy

"[L]anguage is the primary medium through which scientific concepts are understood, constructed, and expressed" (Bialystok 2008, p. 109). Talking about science with peers and with the teacher provides students with opportunities to make sense of their thinking, listen to others' ideas, become aware of multiple perspectives, rethink ideas, evaluate others' ideas, and frame their ideas. Unfortunately, K-12 teachers dominate classroom discussions and do the majority of talking (Mercer et al. 2009; Wyse 2002). Consequently, students do not spend sufficient time producing language and interacting with others in exploratory talk, which allows them to process both language and content more deeply and to negotiate meaning and adjust their language to make it comprehensible to their audience.

2.5.4.2 Writing-Reading in Science Literacy

Research demonstrates that neither reading about science nor hands-on science with no reading or writing is a sufficient method for effective conceptual learning. Writing about science creates opportunities to propose, reinforce, and revise conceptual knowledge and to model different genres (forms/functions) of writing, thereby building the experiential foundations necessary for reading various modes of informational texts (descriptions, cause/effect, problem/solution, procedures, etc.). Integrating science, writing, and reading through authentic inquiry allows for a more engaging, purposeful, reflective, efficient, and effective approach, which improves reading comprehension, conceptual understanding, and academic writing.

2.5.4.3 Representing-Interpreting in Science Literacy

Recently, there has been increased recognition and interest in the ways science ideas are represented (e.g., using a multimodal approach or modes other than words). Research indicates that constructing multiple representations and transforming representations between modes improves representational competence, depth of processing, and conceptual understanding (Yore and Hand 2010). Scientific-literate people construct and use multiple representations (including sketches, diagrams, models, tables, charts, maps, pictures, and graphs), use visual and textual displays to reveal relationships, locate and evaluate information from various textual and digital sources, and choose and use appropriate vocabulary, spatial displays, numerical operations, and statistics.

2.5.5 Information Communication Technologies

Scientists do science with technologies and are limited by the available technologies. ICT allow scientists to cooperate and share databases at a distance, construct new knowledge, and coauthor research reports without being in the same room. Scientists and students use and read calculators, analog/digital meters, digital records, cameras, and videos; troubleshoot common problems; and determine potential causes of malfunctions (AAAS 1993). They use twenty-first century ICT—not to be confused with instructional technologies—for accessing, processing, managing, interpreting, and communicating information; understanding, managing, and creating effective oral, written, and multimedia communications; exercising sound reasoning; making complex choices; and understanding connections among systems and are able to frame, analyze, and solve problems (http://www.21stcenturyskills.org).

2.6 Closing Remarks

This revitalized *Vision III* of *Science Literacy for All* has implications for general literacy for citizenship and daily life—engaging *in (participation) and with (confrontation/dialogue)* science—but it does not exclude elite literacy of science-related academic studies and careers, which may be political priorities in some countries. This framework provides theoretical and practical guidance for enhancing scientific literacy proficiency; for updating and refreshing second-generation science education reforms, standards, and benchmarks; for anchoring and conceptualizing research agendas; and for evaluating classroom practices and instructional resources. The success of this vision to achieve these goals involves convincing policy makers, administrators, and teachers of the essential nature of scientific discourse in doing and learning science and its functional role in the public debate about STSE issues. Furthermore, it is important to convince them of the *cognitive symbiosis* between fundamental and derived senses of scientific literacy, the relationships among cognition, metacognition, inquiry, and language; the critical attributes of promising classroom practices; and guidance for enhanced success and uptake of future science education reforms that are achievable by K-12 general and specialized teachers of science.

2.6.1 Relations Between Language in Science and Understanding Science

Several pressing and practical questions arise when you suggest that *Science Literacy for All* or being literate in science involves a serious consideration of literacy and components of language and not just knowing your science! Parents, students, science professors, and science teachers have concerns about the validity of the language-science claim; they want to know the mechanics between language and knowing, and how acceptance of the language-science claim would influence their instructional time and classroom practice. A practical example of media's potential effects on public awareness and understanding of science may illustrate this process: Articles in *Nature* or *Science*, announcements of Nobel Prize recipients, journalistic reported versions (JRV) of recent research findings in *Popular Science*, and opinion editorials in newspapers are clear tests of out-of-school science literacy and can provide most parents' insights into what is involved in being literate in science and the effects of popular media. Few of us would understand all the intricacies of the physics in charge-coupled devices (CCD) that was the basis for Willard Boyle's and George Smith's share of the 2009 Nobel Prize in Physics (Charles Kao also shared in this prize for his development of high-efficiency optical fiber). Nevertheless, with some degree of insight into how language is used in science and the nature of science, we can appreciate this electronic light detector discovery and its related impact on electronics and digital cameras. Clearly, the time between discovery (1969) and application of the CCD in digital cameras (1986) is far longer than many JRVs make it seem. Furthermore, we realize that much evidence, explicit reasoning, and uncertainty have been stripped from television clips and JRVs. However, many knowledgeable students do not realize these differences, and they overgeneralize and ascribe greater certainty than intended by the authors or justified by the evidence (Norris and Phillips 1994; Phillips and Norris 1999).

Underestimating the importance of language in doing science has been a critical barrier to convincing scientists and science teachers of the value of the literacy component in *Science Literacy for All*. Many scientists and science teachers view the functionality of language simply as a reporting device for what is known. It is a much harder task to convince them that language, especially written language, has cognitive and rhetorical functions in constructing understanding and persuading others and that the choice of language can shape what we know. The history of science is rich with examples of how word choice or metaphor selection influenced the understanding of science ideas (explore *Frozen Stars* and *Black Holes*). Furthermore, others posit that in cultures without written forms of language, the knowledge about nature and naturally occurring events is drastically different from those cultures that have written language (Yore 2008).

2.6.2 Promising Classroom Practices

Over the last 20 years, many science educators have realized that hands-on activities are necessary but, when used alone, are insufficient in supporting student learning and meaningful science understanding. Activity mania, the uncritical belief that additional hands-on sensory experiences automatically leads to understanding, has been replaced with the realization that minds-on experiences—including exploratory talk, argumentation, and negotiations—need to scaffold these hands-on activities. Analysis of language-in-learning articles from science-teaching journals indicates high popularity of these ideas, but most recommendations lack supportive theoretical foundations and empirical evidence (Hand et al. 2010). Many second-generation science inquiry programs have adopted a learning cycle or 5E approach that engages, explores, explains, extends, and evaluates students' learning with embedded literacy tasks or instruction focused on knowledge construction, requisite abilities, and metacognition to enhance understanding and develop discipline-specific language functionality.

Romance and Vitale (1992) conducted one of the first programs to explore a systematic integration of language arts and science instruction by replacing the separate basal reading and science programs with a textbook-based, science-content reading program that emphasized hands-on inquiry activities, science processes, and comprehension of informational text. They found that combining instructional times for reading and science using a science textbook program led to improved reading and science test scores and improved affective measures toward these subjects. Their current research has taken the earlier work, expanded its focus to include science writing, and scaled the efforts to include most elementary and middle schools in two very large school districts with similar promising effects on student performance (Romance and Vitale 2006, 2008). Others have demonstrated the value of explicit reading instruction, literacy tasks, and different types of texts and explicit comprehension instruction embedded in science programs to enhance reading comprehension and metacognitive awareness (Holden and Yore 1996; Pearson et al. 2010; Shymansky et al. 2000; Spence et al. 1999).

Embedded literacy instruction and tasks have been successful in addressing the needs and utilizing the cognitive resources of diverse learners in elementary, secondary, and postsecondary settings. Klentschy and Molina-De La Torre (2004) integrated inquiry science and literacy activities around science notebooks involving low socioeconomic elementary schools with a high percentage of English language learners (ELL). Science notebooks were used by students to record their inquiry experiences; collect and interpret data; process and reprocess experiences, mental images, and representations; document construction of ideas in writing; and monitor and regulate their understanding. They found significant differences between participating students and nonparticipating students and significant improvements for grades 4 and 6 science achievement and grade 6 writing; the performance gaps in reading, writing, and science between native English language and ELL students narrowed and became nonsignificant after 5 years of participation (Klentschy et al. n.d.). Revak and Kuerbis (2008) expanded this approach by integrating literacy and mathematics strategies (graphing, writing, reading) with second-generation inquiry modules across five school districts. Analyses revealed that teacher beliefs, self-reported classroom practices, and teaching proficiency had significant effects on grade 5 students' performance in science, mathematics, reading, and writing on a state-wide test.

The Science Writing Heuristic (SWH) approach, a theoretical orientation that emerged from writing-to-learn research, is a practical shift from laboratory work as replication and production of typical reports to a student-focused experience and the construction of knowledge that integrated the nature of science, inquiry, and argumentation (Hand 2007; Hand and Keys 1999). This approach requires learners to pose questions, make claims supported by evidence, consult with experts, and reflect on changes to their original thinking. The SWH emphasizes students' learning role (student template) and the teacher's service role to support and scaffold these negotiations (teacher template) (Hand et al. 2009; Norton-Meier et al. 2008). Hand (2007) summarized the benefits gained in terms of student performance on standardized tests. Furthermore, a meta-analysis of six quantitative studies (Gunel et al. 2007) and a metasynthesis of ten qualitative studies (McDermott and Hand 2010) demonstrated consistently positive evidence for the SWH approach across science topics and educational levels (primary school to university).

Recent research on the promising role of representational competence in learning science has focused on two broad areas: designing and interpreting effective texts for students and student-generated representations as a basis for science learning (Ainsworth et al. 2011; Prain and Waldrip 2010). Research on the first area was originally structured around dual-coding models for print and visual information, but it is now exploring new issues regarding changes in representational options with ICT, multimedia resources, and out-of-school experiences on student learning. Research in the second area has identified the increased demands on teachers' knowledge base and their teaching, assessment, and identification of representational challenges and opportunities posed by different sequences, combinations, and integrations of representational modes in topics. Furthermore, it has become apparent that existing theories and models of multimodal representations do not fully predict or explain the semiotics, systemic functions, cognition, and metacognition observed or involved in learner-constructed representations (Tippett 2011; Yore and Hand 2010).

2.6.3 Second-Generation Science Education Reforms

The new framework for science education in the USA (NRC 2011) propose a new organization of target proficiencies within four strands of knowing, using, and interpreting scientific/technological explanations; generating and evaluating scientific/technological evidence; understanding the nature and development of scientific/technological knowledge and capacities; and participating productively in the practice and discourse of science and engineering across the discipline-specific core ideas in life, earth-space, and physical sciences and technology and engineering. This document identified crosscutting concepts that provide connections among life, earth-space and physical sciences, and science, technology, and engineering: patterns, similarity, and diversity; cause and effect: mechanism and prediction; scale, proportion, and quantity; systems and system models; energy and matter: flows, cycles, and conservation; form and function; and stability and change. This effort to revitalize the science education reforms of the 1990s is much needed and may reenergize the implementation of common standards across diverse K-12 state and local science curricula and instruction.

I was somewhat disappointed that this effort does not capitalize on the cache and social justice of *Science Literacy for All* and the growing and compelling evidence of the essential roles of language (reporting, constructing, persuading) in doing and learning science, the cognitive symbiosis between fundamental literacy in science and scientific understanding, and citizenship leading to fuller participation in the public debate about STSE issues. Bruce Alberts (2010), editor in chief of *Science*, past president of the National Academy of Sciences, and internationally recognized biochemist, stated:

> In this special issue on education, Science focuses on the connection between learning science in school and the acquisition of language and communication skills, emphasizing the benefits of teaching science and literacy in the same classrooms whenever possible. In the United States, this would be a radical proposal. Unfortunately, the great majority of Americans are accustomed to science classrooms where students memorize facts about the natural world and, if they are lucky, perform an experiment or two; in language arts classes, students generally read fictional literature and write about it in fossilized formats.… [When embedding literacy tasks and instruction in science inquiry], it is helpful to distinguish between factual (or informational) and fictional (or narrative) text. Science reading and writing is largely of the former type, and it is this factual, informational text that dominates today's knowledge-everywhere world. (p. 405)

Vision III of *Scientific Literacy for All* provides an integrated framework based on the nature of modern science, constructivist models of learning, and practical classroom pedagogy that could lead to improved student performance and more effective instruction by generalist and specialist teachers of science. The Lawrence Hall of Science's *Seeds of Science/Roots of Reading* at the University of California, Berkeley (Pearson et al. 2010; http://lawrencehallofscience.org/seeds/) is an excellent example of a program designed to embed literacy tasks and instruction in science inquiry and to capitalize on the functionality of language in constructing understanding, reporting these ideas, and persuading others about these ideas using a multimodal approach. *Seeds of Science/Roots of Reading* uses an instructional cycle that incorporates inquiry and specific literacy tasks (do-it, talk-it, read-it, write-it). People looking to revitalize the current reforms would be well served to take Vision III and this program seriously.

References

Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science, 333*(6046), 1096–1097.

Alberts, B. (2010). Prioritizing science education [Editorial]. *Science, 328*(5977), 405.

American Association for the Advancement of Science. (1990). *Science for all Americans: Project 2061*. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy: Project 2061*. New York: Oxford University Press.

Arons, A. B. (1983). Achieving wider scientific literacy. *Daedalus, 112*(2), 91–122.

Bauer, H. H. (1992). *Scientific literacy and the myth of the scientific method*. Champaign: University of Illinois Press.

Bialystok, E. (2008). Learning a second language. In A. S. Rosebery & B. Warren (Eds.), *Teaching science to English language learners: Building on students' strengths* (pp. 107–118). Arlington: NSTA Press.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth: Heinemann.

Carlsen, W. S. (2007). Language and science learning. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 57–74). Mahwah: Lawrence Erlbaum.

Coll, R. K., & Taylor, N. (Eds.). (2009). Exploring international perspectives of scientific literacy: An overview of the special issue [Special Issue]. *International Journal of Environmental and Science Education, 4*(3), 197–200.

Council of Ministers of Education, Canada. (1997). *Common framework of science learning outcomes, K to 12: Pan-Canadian protocol for collaboration on school curriculum*. Toronto: Author.

Cross, R. T. (1999). The public understanding of science: Implications for education. *International Journal of Science Education, 21*(7), 699–702.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 582–601.

diSessa, A. A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction, 22*(3), 293–331.

Fang, Z. (2005). Scientific literacy: A systemic functional linguistics perspective. *Science Education, 89*(2), 335–347.

Fang, Z., & Schleppegrell, M. J. (2010). Disciplinary literacies across content areas: Supporting secondary reading through functional language analysis. *Journal of Adolescent & Adult Literacy, 53*(7), 587–597.

Fensham, P. J. (1985). Science for all. *Journal of Curriculum Studies, 17*, 415–435.

Ford, C. L. (1998). *Educating preservice teachers to teach for an evaluative view of knowledge and critical thinking in elementary social studies*. Unpublished doctoral dissertation, University of Victoria, Victoria, British Columbia, Canada.

Ford, M. J. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*(3), 404–423.

Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education, 30*(1), 1–32.

Ford, C. L., & Yore, L. D. (2012). Toward convergence of metacognition, reflection, and critical thinking: Illustrations from natural and social sciences teacher education and classroom practice. In A. Zohar & J. Dori (Eds.), *Metacognition in science education: Trends in current research* (pp. 251–271). Dordrecht, The Netherlands: Springer.

Ford, C. L., Yore, L. D., & Anthony, R. J. (1997, March). *Reforms, visions, and standards: A cross-curricular view from an elementary school perspective*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Oak Brook, IL. (ERIC Document Reproduction Service No. ED406168)

Good, R. G., Shymansky, J. A., & Yore, L. D. (1999). Censorship in science and science education. In E. H. Brinkley (Ed.), *Caught off guard: Teachers rethinking censorship and controversy* (pp. 101–121). Boston: Allyn & Bacon.

Gunel, M., Hand, B., & Prain, V. (2007). Writing for learning in science: A secondary analysis of six studies [Special issue]. *International Journal of Science and Mathematics Education, 5*(4), 615–637.

Hand, B. (Ed.). (2007). *Science inquiry, argument and language: A case for the Science Writing Heuristic*. Rotterdam: Sense Publishers.

Hand, B., & Keys, C. (1999). Inquiry investigation. *The Science Teacher, 66*(4), 27–29.

Hand, B., Prain, V., & Yore, L. D. (2001). Sequential writing tasks' influence on science learning. In P. Tynjälä, L. Mason, & K. Lonka (Eds.), *Writing as a learning tool: Integrating theory and practice* (Vol. 7 of Studies in writing, pp. 105–129). Dordrecht: Kluwer/Springer.

Hand, B., Yore, L. D., & Prain, V. (Eds.). (2006). Natural science, cognitive science and pedagogical influences on science literacy: Empowering research and informing instruction [Special issue]. *International Journal of Science Education, 28*(2/3), 99–314.

Hand, B., Norton-Meier, L., Staker, J., & Bintz, J. (2009). *Negotiating science: The critical role of argument in student inquiry, grades 5–10*. Portsmouth: Heinemann.

Hand, B., Yore, L. D., Jagger, S., & Prain, V. (2010). Connecting research in science literacy and classroom practice: A review of science teaching journals in Australia, the UK, and the United States, 1998–2008. *Studies in Science Education, 46*(1), 45–68.

Hines, P. J., Wible, B., & McCartney, M. (Eds.). (2010). Learning to read, reading to learn [Special issue]. *Science, 328*(5977), 447.

Holbrook, J., & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*(11), 1347–1362.

Holden, T. G., & Yore, L. D. (1996, March–April). *Relationships among prior conceptual knowledge, metacognitive awareness, metacognitive self-management, cognitive style, perception-judgment style, attitude toward school science, self-regulation, and science achievement in grades 6–7 students*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, St. Louis, MO.

Hurd, P. D. (1958). Science literacy: Its meaning for American schools. *Educational Leadership, 16*, 13–16 & 52.

International Technology Education Association. (2007). *Standards for technological literacy: Content for the study of technology* (3rd ed.). Reston: Author.

Kelly, G. J. (2007). Scientific literacy, discourse, and knowledge. In C. Linder, L. Östman, & P.-O. Wickman (Eds.), *Proceedings of the Linnaeus Tercentenary Symposium* (pp. 47–55). Uppsala: Geotryckeriet.

Klentschy, M. P., & Molina-De La Torre, E. (2004). Students' science notebooks and the inquiry process. In E. W. Saul (Ed.), *Crossing borders in literacy and science instruction: Perspectives on theory and practice* (pp. 340–354). Newark: International Reading Association/National Science Teachers Association.

Klentschy, M. P., Garrison, L., & Amaral, O. M. (n.d.). *Valle Imperial Project in Science (VIPS) four-year comparison of student achievement data 1995–1999* (Unpublished project report).

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education, 84*(1), 71–94.

Linder, C., Östman, L., & Wickman, P.-O. (Eds.). (2007). Promoting scientific literacy: Science education research in transition. In *Proceedings of the Linnaeus Tercentenary Symposium*. Retrieved from http://www.fysik.uu.se/didaktik/lsl/Web%20Proceedings.pdf

McDermott, M. A., & Hand, B. (2010). A secondary reanalysis of student perceptions of non-traditional writing tasks over a ten year period. *Journal of Research in Science Teaching, 47*(5), 518–539.

McEneaney, E. H. (2003). The worldwide cachet of scientific literacy. *Comparative Education Review, 47*(2), 217–237.

Mercer, N., Dawes, L., & Staarman, j. K. (2009). Dialogic teaching in the primary science classroom. *Language and Education, 5*, 353–369.

Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. *Daedalus, 112*(2), 29–48.

Moje, E. B. (2007). Chapter 1: Developing socially just subject-matter instruction: A review of the literature on disciplinary literacy teaching. *Review of Research in Education, 31*(1), 1–44.

Moje, E. B. (2008). Foregrounding the disciplines in secondary literacy teaching and learning: A call for change. *Journal of Adolescent & Adult Literacy, 52*(2), 96–107.

Norris, S. P., & Phillips, L. M. (1994). Interpreting pragmatic meaning when reading popular reports of science. *Journal of Research in Science Teaching, 31*(9), 947–967.

Norton-Meier, L., Hand, B., Hockenberry, L., & Wise, K. (2008). *Questions, claims, and evidence: The important place of argument in children's science writing*. Portsmouth/Arlington: Heinemann/NSTA Press.

Pearson, P. D., Moje, E. B., & Greenleaf, C. (2010). Literacy and science: Each in the service of the other [Special issue]. *Science, 328*(5977), 459–463.

Pella, M. O., O'Hearn, G. T., & Gale, C. W. (1966). Referents to scientific literacy. *Journal of Research in Science Teaching, 4*(3), 199–208.

Phillips, L. M., & Norris, S. F. (1999). Interpreting popular reports of science: What happens when the reader's world meets the world on paper? *International Journal of Science Education, 21*(3), 317–327.

Phillips, L. M., & Norris, S. P. (2009). Bridging the gap between the language of science and the language of school science through the use of adapted primary literature. *Research in Science Education, 39*(3), 313–319.

Prain, V., & Waldrip, B. (Eds.). (2010). Representing science literacies [Special issue]. *Research in Science Education, 40*(1), 1–101.

Revak, M., & Kuerbis, P. J. (2008, January). *The link from professional development to K-6 student achievement in science, math, and literacy*. Paper presented at the annual international meeting of the Association for Science Teacher Education, St. Louis, MO.

Roberts, D. A. (2007). Scientific literacy/science literacy. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research in science education* (pp. 729–780). Mahwah, NJ: Lawrence Erlbaum.

Romance, N. R., & Vitale, M. R. (1992). A curriculum strategy that expands time for in-depth elementary science instruction by using science-based reading strategies: Effects of a year-long study in grade four. *Journal of Research in Science Teaching, 29*(6), 545–554.

Romance, N. R., & Vitale, M. R. (2006). Science IDEAS: Making the case for integrating reading and writing in elementary science as a key element in school reform. In R. Douglas, M. P. Klentschy, K. Worth, & W. Binder (Eds.), *Linking science and literacy in the K-8 classroom* (pp. 391–405). Arlington: NSTA Press.

Romance, N. R., & Vitale, M. R. (2008). *NSF/IERI science IDEAS project* (Technical Report 0228353–0014). Boca Raton: Florida Atlantic University.

Science Council of Canada. (1984). *Science for every student: Educating Canadians for tomorrow's world*. Ottawa: Ministry of Supply and Services.

Shamos, M. H. (Ed.). (1995). *The myth of scientific literacy*. New Brunswick: Rutgers University Press.

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content-area literacy. *Harvard Educational Review, 78*(1), 40–59.

Shen, B. S. P. (1975). Science literacy: The public understanding of science. In S. B. Day (Ed.), *Communication of scientific information* (pp. 44–52). New York: S. Karger.

Shymansky, J. A., Yore, L. D., & Hand, B. (2000). Empowering families in hands-on science programs. *School Science and Mathematics, 100*(1), 48–56.

Singapore Ministry of Education. (2010). *Subject syllabuses – Sciences*. Retrieved from http://www.moe.gov.sg/education/syllabuses/sciences/

Snow, C. E. (2010). Academic language and the challenge of reading for learning about science [Special issue]. *Science, 328*(5977), 450–452.

Spence, D. J., Yore, L. D., & Williams, R. L. (1999). The effects of explicit science reading instruction on selected grade 7 students' metacognition and comprehension of specific science text. *Journal of Elementary Science Education, 11*(2), 15–30.

Stoddart, T., Pinal, A., Latzke, M., & Canaday, D. (2002). Integrating inquiry science and language development for English language learners. *Journal of Research in Science Teaching, 39*(8), 664–687.

Tippett, C. D. (2011). *Exploring middle school students' representational competence in science: Development and verification of a framework for learning with visual representations*. Unpublished doctoral dissertation. University of Victoria, Victoria, BC, Canada. Available at http://hdl.handle.net/1828/3250

United States National Academy of Engineering. (2002). *Technically speaking: Why all Americans need to know more about technology*. G. Pearson & A. T. Young (Eds.). Committee on Technological Literacy, National Academy of Engineering, National Research Council. Washington, DC: The National Academies Press.

United States National Research Council. (1996). *The national science education standards*. Washington, DC: The National Academies Press.

United States National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K-8*. Committee on Science Learning, Kindergarten through Eighth Grade. R. A. Duschl, H. A. Schweingruber, & A. W. Shouse (Eds.). Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

United States National Research Council. (2011). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Committee on Conceptual Framework for New Science Education Standards. H. Quinn & H. A. Schweingruber (Eds.). Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

van den Broek, P. (2010). Using texts in science education: Cognitive processes and knowledge representation [Special issue]. *Science, 328*(5977), 453–456.

Webb, P. (2009). Towards an integrated learning strategies approach to promoting scientific literacy in the South African context [Special issue]. *International Journal of Environmental and Science Education, 4*(3), 313–334.

Webb, P. (2010). Science education and literacy: Imperatives for the developed and developing world [Special issue]. *Science, 328*(5977), 448–450.

Wyse, D. (2002). *Becoming a primary school teacher*. London: RoutledgeFalmer.

Yore, L. D. (2008). Science literacy for all students: Language, culture, and knowledge about nature and naturally occurring events [Special issue]. *L1—Educational Studies in Language and Literature, 8*(1), 5–21. Retrieved from http://l1.publication-archive.com/show?repository=1&article=213

Yore, L. D., & Hand, B. (2010). Epilogue: Plotting a research agenda for multiple representations, multiple modality, and multimodal representational competency [Special issue]. *Research in Science Education, 40*(1), 93–101.

Yore, L. D., Bisanz, G. L., & Hand, B. (2003). Examining the literacy component of science literacy: 25 years of language arts and science research. *International Journal of Science Education, 25*(6), 689–725.

Yore, L. D., Florence, M. K., Pearson, T. W., & Weaver, A. J. (2006). Written discourse in scientific communities: A conversation with two scientists about their views of science, use of language, role of writing in doing science, and compatibility between their epistemic views and language. *International Journal of Science Education, 28*(2/3), 109–141.

Yore, L. D., Pimm, D., & Tuan, H.-L. (Eds.). (2007a). Language – An end and a means to mathematical literacy and scientific literacy [Special issue]. *International Journal of Science and Mathematics Education, 5*(4), 557–769.

Yore, L. D., Pimm, D., & Tuan, H.-L. (2007b). The literacy component of mathematical and scientific literacy [Special issue]. *International Journal of Science and Mathematics Education, 5*(4), 559–589.

Chapter 3
Moving the Essence of Inquiry into the Classroom: Engaging Teachers and Students in Authentic Science

Barbara A. Crawford

3.1 Introduction

How can teachers help children understand what science is, what science is not, and develop images of how scientists think and work? How can we create science classrooms where children use observations as evidence and creatively try to understand the world? My long-time career interests involve trying to figure out how we can change the way science is taught in most classrooms across the United States. First and foremost, I am a teacher. As a former public school science teacher, I taught life science and biology, physical science, chemistry, and physics to children aged 12–18 in the United States for over 16 years. For the past 15 years, I have worked with preservice and in-service science teachers in designing classrooms that provide children an opportunity to gain an interest in science, use science inquiry, and learn about nature of science. My passion is to engage children in actively understanding what science is, not by trying to memorize the massive amount of facts in science textbooks but through investigation, by grappling with data, and in becoming critical thinkers. Ultimately, I would like all children to be motivated to learn about science and how to do science and to develop into lifelong learners of science. The main question driving this chapter is how can we move *science as inquiry* into the science classroom?

Decades ago, inquiry had been posed as an effective method of engaging students in real-world experiences (Dewey 1938). Although the U.S. reform documents (American Association of the Advancement of Science [AAAS] 1989, 1993; National Research Council [NRC] 1996, 2000) emphasize inquiry as a central strategy

---

B.A. Crawford (✉)
Department of Mathematics and Science Education, The University of Georgia,
212 Aderhold Hall, Athens, GA 30606, USA
e-mail: barbarac@uga.edu

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_3,

for teaching science, the reality is that most teachers do not use inquiry-based instruction in their classrooms. Further, there is little empirical evidence of effective ways to support teachers in understanding the nature of scientific inquiry and how to implement inquiry in science classrooms.

My view of teaching science as inquiry, at its most basic level, involves helping children to find answers to questions using logic and evidence. Inquiry involves going beyond the simple asking of questions, to trying to figure out how to make sense of data to answer a scientifically based question. Aligned with guidelines in education reform documents in the United States, the learner asks and answers scientifically oriented questions about the natural world, gives priority to evidence in responding to questions, comes up with explanations using data as evidence, connects explanations to scientific knowledge, and communicates and justifies explanations (NRC 2000). Similar to what a scientist does, the student figures out something by himself/herself, *with the guidance of the teacher*, by making sense of observations, the text in a book, the images on a computer screen, or the data gathered during an investigation. At the heart of inquiry is the learner herself, *grappling with data* and making sense of some event or phenomenon in a social environment.

Inquiry-based teaching is a complex and sophisticated way of teaching that requires the teacher to have an adequate understanding of scientific inquiry and the nature of science and inquiry-based teaching approaches (Crawford 2000, 2007). The kinds of inquiry conducted in classrooms should reflect a range of scientific work beyond that of experiments, including using observational methods and historical reconstruction (Duschl et al. 2007; Millar 1989). This kind of teaching requires significant professional development and support. Many teachers do not have adequate preparation in science to create a successful inquiry-based environment (Krajcik et al. 2000), or they simply may not understand what inquiry is (Anderson 2002), or not have beliefs and views that support this kind of teaching (Gallagher 1991; Lederman 1992; Luft 2001). The problem is more acute at the elementary and middle school levels, where teachers generally have little or no formal science training and lack familiarity with the fundamentals of scientific inquiry (Loucks-Horsley et al. 2003).

3.2 Theoretical Framework

The theoretical framework guiding the design of my research and assertions offered in this chapter include two main areas, social constructivism and authenticity.

3.2.1 Social-Constructivist Perspectives of Learning

This view of learning aligns with the recent framework and assessments in the PISA project (see Bybee et al. 2009) in which context is important. I view learning from a social-constructivist perspective, taking the position that knowledge is developed in the context of personal experiences in collaboration with others (Driver 1989; Driver et al. 1994; Vygotsky 1978). In a process of grappling with data to make sense of it and through negotiation of ideas with peers and experts in a social context, the learner gains an individual and internalized understanding of science.

3.2.2 Authenticity

The *construct of authenticity* is an important theoretical construct that underpins my views of teaching science as inquiry in classrooms. Authenticity relates to classroom practices similar to those in which scientists engage, including epistemological and reasoning aspects (Chinn and Malholtra 2002). Authenticity in the science classroom demonstrates or replicates the kinds of work scientists do and is relevant to students (Braund and Reiss 2006; Dewey 1938; Hodson 1998; Roth 1995). Just moving a scientist's science into classrooms without some modification of the science content and methods to match the developmental level of students is not appropriate. The authentic aspect of the science classroom-based instruction includes transforming the traditional static classroom instruction to include a more dynamic interaction between the teacher and the learner, as suggested by Rahm et al. (2003). The importance of the time, place, and situation related to the authentic nature of a science-learning environment is highlighted by educational learning theorists (Brown et al. 1989).

An example of authenticity in school science is provided by Rosebery et al. (1989) in the Cheche Konnen project, a study that provided some evidence for the importance of connecting inquiry to the lives of diverse children. The learning environment was transformed from traditional worksheet-driven instruction to authentic inquiry for these Haitian middle-level students when they investigated the drinking water in their school and came up with their own questions. Important considerations include the following: what are the goals of science instruction? For whom is science authentic? What kinds of developmentally and culturally appropriate experiences are feasible in classroom situations? How can teachers address aspects of the nature of scientific inquiry and attend to the developmental and cultural needs of learners?

3.3 Building upon a Research Agenda Focused on Inquiry

The centerpiece of my research agenda is understanding and developing viable ways to support teachers and students in using and understanding inquiry. Together with colleagues, I have carried out a series of empirical studies over the last several years, investigating how learners, in a range of settings and levels, gain understandings of the processes, nature, and subject matter of science through inquiry.

3.3.1 The Nature of the Studies

These studies include (1) *A Middle School Community of Learners*, a qualitative study of my own middle-level students engaged in open-ended projects designed by the students in collaboration with experts outside the classroom (Crawford et al. 1999); (2) *The Community Slough Project*, a case study of an experienced high school ecology teacher who engaged his students in an authentic investigation of a local river slough with university experts (Crawford 2000); (3) *High School Students' Authentic Summer*, a study investigating high school science students participating in a summer-long research internship at a university and the influence of the experiences on their ideas about scientific inquiry and nature of science (Bell et al. 2003); (4) *The Authentic Research Seminar for Preservice Teachers*, a study of adults in a graduate-level science teacher education course that integrated an authentic research experience with a campus-based, theory-driven seminar, rich in opportunities for discussion and reflection (Schwartz et al. 2004); and (5) *Teaching Methods and Modeling*, a study of undergraduate college students preparing to teach secondary science, as they designed investigations of real-world phenomena, then built and tested models of scientific phenomena using modeling software (Crawford and Cullin 2004).

3.3.2 Assertions from These Studies

Drawing from these studies, there is growing evidence for a proposed model of inquiry learning and teaching science in classrooms incorporating three components: active investigation, authenticity, and reflection. A summary of some key assertions based on prior work includes:

- Authenticity, in its various forms, can provide a valuable context for reflection on aspects of the nature of scientific inquiry (i.e., Schwartz et al. 2004; Schwartz and Crawford 2004).
- Authentic contexts are those that support the learner in making sense of naturally occurring events and constructing compelling explanations that justify the time, resources, and effort needed to set inquiry into action (Crawford et al. 2005).
- Authentic science in classrooms enables students to engage in investigations that are meaningful to them (e.g., Crawford et al. 1999; Crawford 2000; Krajcik et al. 1998).
- Guidance by the classroom teacher to facilitate students in collaborating with others is critical (Crawford 2000; Crawford et al. 1999).
- Authority of the teacher may impede, rather than support, the process of negotiating ideas, and the willingness of the teacher to shift authority to students is critical for success (Crawford et al. 1999).

In our research team's recent efforts to understand how to effectively support teachers and facilitate students in learning to do scientific inquiry, through inquiry, and *about* inquiry, we designed a multiyear project that combines an authentic scientific investigation, innovative inquiry resources and tools, an interactive data-based website, and teacher professional development. The basic idea is to immerse teachers (as learners) and their students in an authentic science investigation. In this case, the investigation involves classroom students helping scientists learn about past environments. The learning *of* science in this project includes core concepts related to geology and evolutionary theory (Catley et al. 2004). Teachers involve their students in contributing data to the authentic scientific investigation and in learning about multidisciplinary concepts such as uniformatarianism, superposition, diversity, structure-function, deep time, environments, change over time, finding patterns in data, and aspects of nature of science.

In this chapter, I will present some of our preliminary findings from a project designed to provide authentic experiences for teachers and students and to help teachers bring their inquiry experiences into their classrooms. I will present evidence of the kinds of things teachers learned and how teachers began to translate their knowledge of inquiry to their classrooms and, in turn, how students were engaged in authentic science experiences and what students learned about scientific inquiry and key science concepts.

3.4 The Fossil Finders Project: Research to Practice

In January 2008, researchers from the Cornell University Department of Education and the Paleontological Research Institution (PRI) in Ithaca, New York, collaborated to actively support teachers and children in learning about science inquiry and concepts related to evolutionary theory. Th*e Fossil Finders* project strives to bridge research to practice by engaging teachers and children in classrooms carrying out an authentic investigation of Devonian fossils. The goals of the project include helping children and teachers to understand how scientists use evidence to build theory, enhance abilities to do inquiry, and stimulate interest in paleontology, biology, and geology in target demographics (females, low socioeconomic status [SES] and English language learners [ELL] students). Ultimately, the *Fossil Finders* project aims to provide a viable national model for creating effective partnerships between science museums, science education researchers, and teachers and children in classrooms. These partnerships could be effective in supporting teachers in providing inquiry-based, authentic science to their students. The theoretical framework guiding our work is that learning is associated with meaningful activities. This view is embodied in the constructs of social constructivism, situated cognition, and cognitive apprenticeships (Brown et al. 1989; Lave and Wenger 1991).

In the *Fossil Finders* project, children from two grade spans (5th/6th and 7th/9th) receive samples of rock (i.e., samples of shale from an Upstate New York State outcrop) shipped to their classrooms. Teachers help children look for the fossils in the rock, identify the fossils they find, and measure the fossils and fossil fragments and note other characteristics (see Appendix for a sample lesson). Teachers and

Table 3.1 Roles in creating an authentic inquiry-based science classroom

Collaborators	Various roles
Scientists	Provide research question
	Develop protocols for analyzing the fossil data
	Use student-contributed data to develop scientific explanations
	Provide tools and materials
	Develop explanations (reconstruct the geologic past of central New York)
Science education researchers	Provide inquiry teaching strategies
	Explicit nature of science support
	Curriculum development
	Liaison between scientists and teachers
Teachers	Engage with scientists (in studying past environments)
	Facilitate students in gathering and analyzing data (identifying and measuring fossils, analyzing aggregate data)
	Help students understand key science concepts and NOS
	Provide feedback on lessons and pedagogy
	Change agents in classrooms
Students	Identify fossils in rock samples
	Enter their class data into an online database
	Analyze data
	Work with their peers
	Help scientists develop explanations (reconstruct the geologic past of central New York)
	Ask their own questions

students use an interactive website and submit their own data to an emerging database. A key focus is on classrooms with a high proportion of underrepresented groups of children (whose race and gender are not well represented in the sciences). The idea of authenticity is front and center in the instructional materials. For example, teachers are encouraged to say to their students, “We will be the first ones to collect this (fossil) data. Nobody else has looked at these samples and knows what will be found! We will use this data to learn about science, share with scientists and other classes, and perhaps answer some questions of our own or questions posed by other classes.”

The *Fossil Finders* project provides a context for students to learn about how the Earth has changed throughout time. Students begin to piece together an understanding that New York State (in the northeastern part of the United States) once had very different environmental conditions from today. Teachers help students to understand that the area where people live now was not always as it is today. In fact, instead of fresh water lakes and farmlands, there is evidence of a warm shallow sea. This understanding of a past environment serves to lay the groundwork to develop more sophisticated understandings of environmental change.

Teachers, scientists, science education researchers, and students all collaborate to answer a driving question and enter data on a website (www.fossilfinders.org). See Table 3.1 for the various roles of collaborators.

3.5 Supporting Teachers Through Professional Development

To support teachers in understanding inquiry, we planned and carried out a summer institute in Ithaca, New York. We used the research on professional development programs (i.e., Loucks-Horsley et al. 2003) and our own research on inquiry-based teaching (Crawford 2000, 2007) to inform the design of our teacher professional development. In particular, Loucks-Horsley et al. (2003) describe strategies that include immersion in inquiry into science and mathematics and immersion into the world of scientists. In the *Fossil Finders* project, the focus of our designed professional development involves an authentic scientific setting conducive to translation to a science classroom, combined with modeling an inquiry approach with explicit connections to aspects of nature of science. The centerpiece of the *Fossil Finders* project is the authentic paleontological investigation examining how sea life responded to changes in the environment during the Devonian Period in central New York.

During the first summer of the project, ten New York State teachers participated in the 5½-day summer institute. During this time, we involved teachers in four field trips; lessons and discussion in a Geology classroom of how to find, identify, and measure fossils; how to translate ideas of inquiry and nature of science into classrooms; sessions of the various versions of inquiry in the national science education standards; a tour of the Museum of the Earth in Ithaca, NY, highlighted by a behind-the-scenes look at the work of paleontologists and the world class PRI fossil collections; and evening discussions of ELL strategies and a session on how to deal with controversial issues of teaching about evolution.

3.6 Collecting Multiple Forms of Data

To track changes in teachers' and students' views of inquiry, NOS, and evolutionary concepts and of teachers' practice in their classrooms, we used a mixed methods approach consisting of a qualitative, interpretive approach informed by Creswell (1998) and Miles and Huberman (1994), and quantitative data based on pre-post questionnaires (Woodruff et al. 2011). The data on teacher change included multiple sources. First, we administered the pre-post teacher questionnaire to all ten teachers on the first day of the summer institute and immediately following the institute. The pretest was administered the afternoon the teachers arrived on campus. The pre- and posttests were identical. Teachers completed the pretest using laptop computers provided to them the first day and the final day of the summer institute. We asked teachers not to use outside sources in responding to questions. Second, we conducted a semi-structured postinstitute teacher interview. Third, we obtained videotape data of all ten teachers in their classrooms, taken prior to the summer institute as a baseline for inquiry teaching. Fourth, our team videotaped all teachers in their classrooms as they carried out the *Fossil Finders* inquiry-based instruction. Fifth, we used the teacher application materials to determine initial views and motivation for participating in the project. We triangulated analyses of the multiple data sources.

To assess children's views of inquiry and nature of science and knowledge of science concepts, the research team and external evaluation team identified and developed student instruments that specifically addressed the goals and content of the *Fossil Finders* project. Several valid and reliable items were identified and used, with permission, to construct instruments for the project. Additional items were developed by *Fossil Finders* project personnel in order to assess content for which no appropriate existing, valid items were available. The *Fossil Finders Student Questionnaire Form E* was developed for elementary students (Grades 5 and 6) and included two subscales and six questions collecting demographic data. The first subscale, "Content Form E (elementary level)," addressed *Fossil Finders* science content knowledge and included 14 multiple-choice items. The second, "VNOS Form E," subscale was adapted with permission from the *Views of Nature of Science Elementary School Version (VNOS-E)* (Lederman and Lederman 2005) and included six open-response items. Form S (secondary level) and Form E of the student questionnaire can be available from the author upon request.

3.7 Teachers' Changes in Views and Knowledge and Practice

In our preliminary data analyses, we detected positive changes in all ten teachers' views of inquiry, NOS, and of earth and evolutionary concepts, pre to post. Following the *Fossil Finders* professional development experience, teachers demonstrated a more informed understanding of some aspects of NOS and science inquiry, including how scientists reach different conclusions from the same evidence, and the importance of data and its relationship to evidence. For example, one 5th-grade teacher, WK developed a more informed understanding of the nature of scientific inquiry, in addition to targeted science concepts. There is evidence that at the beginning of the professional development, WK held the naïve idea that there is a *single* scientific method – in other words, scientists always follow one particular set of steps (a misconception depicted in many science textbooks). Evidence of this view is the response on the prequestionnaire. WK wrote, "Yes, I think it does need to follow these steps to ensure an accurate result." Through her experiences in the summer institute, WK developed a more informed understanding that scientists use multiple methods, and they selected a particular research method, depending on the type of research question investigated. Regarding inquiry, many teachers, at first, demonstrated a "confused" view of inquiry and equated inquiry with simply, "hands-on teaching." For example, a teacher initially stated, "inquiry teaching is hands-on work, that includes questioning and discovering (VM)." The problem with this view is that teachers may miss the important aspect of inquiry-based teaching in which a teacher moves students from simply collecting data, to using data as evidence in developing explanations, and connecting their explanations to scientific views.

3.8 Teachers Translating Their Views to Their Classrooms

Moving beyond enhancing teachers' knowledge, our research team is interested in the question, *what is the evidence of teachers translating their knowledge and views of inquiry to their own classrooms*? Following the summer institute, we visited teachers' classrooms and videotaped several lessons associated with the *Fossil Finders* curriculum. Representative examples of how students engaged in essential features of inquiry in their science classrooms during the *Fossil Finders* project appear in Table 3.2.

To assess changes in teaching practice, we videotaped a lesson suggested by each teacher earlier that spring. We used this lesson as a baseline to detect changes, if any, in their teaching approaches, by comparing with postvideos. Preliminary analyses of pre-post lessons revealed that all teachers demonstrated at least some positive movement toward using more reformed-based ways of teaching, including using more than one or two features of inquiry-based instruction (see Capps and Crawford 2010). Given the complexity of teaching, we understand the limitations of using one videotaped lesson (pre) as a means to assess a teacher's practice. Videotapes of single lessons cannot capture all the nuances of teaching. However, we also analyzed teacher responses to written questions and conversations to triangulate our data and attempted to portray the most accurate representation of these teachers' view of teaching science.

Table 3.2 Essential features of inquiry in the *Fossil Finders* classroom (Adapted from NRC 2000)

Feature (abbreviation)	Description of feature	Example in classroom
SQ scientific question	Learner engages in answering a *scientifically oriented question*	Learner asked to help answer, how did sea life respond to the environment in New York State, nearly 400 million years ago?
DE data as evidence	Learners *gathers (or is given) data to use as evidence* for answering the question	Learner identifies and measures brachiopods, clams, trilobites, and other fossils he or she finds in shale samples
EE evidence-based explanations	Learner grapples with and analyzes data to develop *evidenced-based explanations* and answers by looking for patterns and drawing conclusions	Learner makes graphs of kinds and size of fossils, enters his or her data into an online database, uses data as evidence, using fossils as clues to what the area was like nearly 400 million years ago
SE scientific explanations	Learner connects the *explanations* with those explanations and concepts developed by the *scientific community*	Learners connects her explanations of the past environment with those of paleontologists and geologists
CD communicating and defending	Learner communicates, justifies, and *defends explanations*	Learners discuss class findings among peers and post a report on the project *Fossil Finders* website in the student-scientists area

In observing teachers enacting the *Fossil Finders* curriculum and investigation, there were many instances of teachers delving deeper into the use of evidence with their students. Prior to the PD, one fifth-grade teacher, Kristen, involved her students in "hands-on" activities; however, the use of essential features of inquiry was limited to that of "asking students questions." For many teachers, we observed them asking primarily closed-ended, "yes" or "no" questions to their students. Many questions were not scientifically oriented. After the professional development, there was evidence that teachers made a point to ask students to think about the difference between observations and inferences. Specifically, Kristen began to ask more scientifically oriented questions. She began to press her students to consider the use of data as evidence for their explanations.

3.8.1 Kristen's Teaching Practice: Pre

Prior to the professional development, Kristen's teaching was characterized as *hands-on and issue-based instruction, with an emphasis on vocabulary words*. In her application to the program, Kristen described a unit on recycling. Her main objective was to instill lifelong stewardship. She explained that "The Kickoff Lesson" was presented by a guest speaker from our community – Greta Garbage who visited our class and spoke about the significance of recycling and the consequences of landfills. The lesson included several read aloud mini-lessons, which led to small group discussions and independent reflection. What Kristen called "experiments" in her unit were indeed interesting, but not aligned with our view of inquiry-based teaching. Classroom videotape data showed Kristen asking her students questions; however, these questions were generally fact-based questions, such as "What are the differences between reptiles and amphibians," or questions that can be answered by looking up information in textbooks: "Can amphibians breathe water? That's the question we need to answer."

Analysis of Kristen's prevideo showed her 5th-grade students working at various lab stations. Students moved from one station to the next, after completing tasks. At the stations, students made observations of dragonfly wings under a microscope, looked at reptiles (live turtles), completed a worksheet on photosynthesis, and a worksheet on amphibians. Students worked quietly in groups of three. In the video, one can hear an aide speaking Spanish with a student in the background. At the photosynthesis station, Kristen asked students to write down definitions and copy the chemical equation for photosynthesis. However, the teacher did not probe students for their understanding of photosynthesis or encourage them to ask questions at the various stations.

In this prelesson, although students were busy "doing things," there was limited evidence of the essential features of inquiry in this classroom. The teacher did begin her instruction by asking questions of her students. Beyond the initial questions, the teacher did not scaffold her students in answering these questions (unless she expected them to go to outside resources, but this was not discussed in the video).

3.8.2 Kristen's Teaching Practice: Post

Videotaped classroom observations following the *Fossil Finders* professional development showed evidence of Kristen involving her students in inquiry beyond that of asking them closed-ended questions. In the lesson description below, Kristen helps students to distinguish between observations and inferences.

> MV_093008_TrickyTracks.wmv
> Teacher puts Tricky Tracks transparency slide on overhead projector. Students write in their journal responses to the prompt, "What do I see?"
>
> Students make Journal entry; included some illustration, and students discussed with peers what they observed.
>
> ~8:46 – Teacher Prompted Group Discussion
> Tell the size or nature of the organism?
> Teacher asks students to recount their inferences. How many of you thought there were two types of animals? Why? Are you making inferences about size of animal based on size of footprints? Are there two individuals?
> ~10:39 – Connecting observations to stories. Past experiences – walking in the snow.
>
> Journal Entry: Sequence of events explaining what is observed on the slide.
>
> Following class discussion, teacher asks, if they are dinosaurs, then what were the dinosaurs doing? Teacher (class consensus?) speaks of the tracks as representing dinosaur tracks.
> She asks, why are the dinosaurs fighting? For food?
> If they are fighting over food, what did environment look like? What did these dinosaurs eat?

In the lesson segment above, Kristen, through a series of questions and follow-up prompts, facilitates her students in developing explanations based on evidence, an essential feature of scientific inquiry. She also scaffolds her students in distinguishing between observations and inferences, a tenet of nature of science. One of the misconceptions that can get in the way of children understanding evolutionary theory is the lack of understanding how scientists develop a theory. A scientific theory is a way to explain a phenomenon and is not just an educated guess, but built on a great deal of evidence over time.

These preliminary findings from the first year of the Fossil Finders project provide evidence of improvement in teachers' views of science, understandings of nature of science, and understandings of some evolutionary concepts, and abilities to use inquiry-based approaches in their teaching practice following the professional development. We cannot claim cause and effect, but it is likely teachers' growth and apparent changes in practice are associated with their professional development experiences and use of the Fossil Finders curricular materials. We are beginning to find more evidence of these changes in teacher practice, and our current studies reveal more robust findings.

3.9 Impact on Student Learning of Scientific Inquiry

Ultimately, we are interested in the impact of inquiry-based instruction on student learning of science concepts, principles, and nature of science. Specifically, do students understand more about what science is, from engaging in the *Fossil Finders*

Table 3.3 Form E (elementary) respondent student gender and race/ethnicity

	Participant			Comparison		
Race/ethnicity	Female	Male	Total	Female	Male	Total
African-American	16	17	33	26	21	47
Native American/Alaskan Native	1	2	3	3	1	4
Asian or Pacific Islander	1	2	3	0	1	1
Hispanic/Latino(a)	3	0	3	22	10	32
White (not Hispanic/Latino)(a)	11	16	27	17	25	42
Other	10	7	17	8	13	21
Total	42	44	86	76	71	147

inquiry-based instruction? To assess the effectiveness of the Pilot *Fossil Finders* materials, we constructed student assessments (pre and post). The developed instruments have three scales: content science knowledge items, NOS items, and inquiry items. We administered these assessments to students in our Pilot teachers' classrooms, at the beginning of the school year 2008 and near the end of the school year Spring 2009. Additionally, we asked our teachers to select a comparison teacher (not involved in the project, but teaching similar classes in the same grade level and in the same school) to provide a control group of students. The comparison teacher administered the pre- and posttests to classes similar to those of the *Fossil Finders* teachers.

In total, 86 fifth-grade students participated in the first year of the *Fossil Finders* program, representing a wide range of race/ethnicity (see Table 3.3 for displays of respondent race/ethnicity and gender for participant and comparison groups). As shown in Table 3.3, most of the Form E (elementary) prequestionnaire respondents indicated either African-American (32% of participant; 38% of comparison) or White (29% of participant; 31% of comparison) as their race/ethnicity. Male and female respondents were relatively evenly distributed for each group.

Significant differences were found between the *Fossil Finders* elementary students' and comparison students' postcontent knowledge scores and understanding of certain aspects of the nature of science and inquiry (see Woodruff et al. 2011). In an effort to provide a control in the study, the students in the comparison classrooms had science lessons during the same time period as the children in the project classrooms, and these lessons related to similar subject matter. But we did not have specific information on the exact lessons used in each comparison classroom, only that the subject matter was similar. While comparison group students' performance improved on the content knowledge subscale, no improvement was seen in their understanding of inquiry and NOS. Further, ANOVA results suggest that differences in gains between *Fossil Finders* students and comparison students were attributable to exposure to *Fossil Finders* materials. See Fig. 3.1 for a display of students' pre- and post-Rasch mean scores of change in views of nature of science by *Fossil Finders* participation. A summary of the preliminary, first-year data analyses appears below:

- *Fossil Finders* elementary student mean scores improved on all but one item on the *subject matter knowledge assessment*, with 4 (of 13) items demonstrating

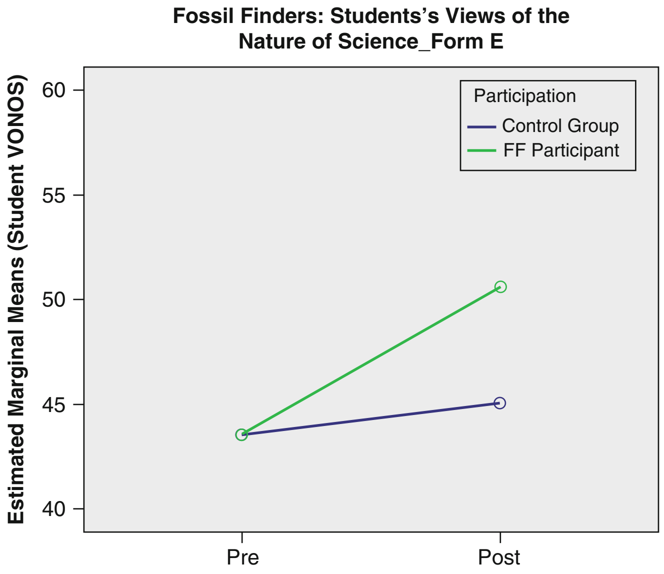


Fig. 3.1 Students' pre and post Rasch mean scores on "VNOS Form E" by Fossil Finders participation

statistically significant gains. Students demonstrated a better understanding of important Earth science and evolutionary concepts, including (a) impact of environmental change on organisms, (b) the law of superposition, and (c) fossil-forming processes.

- *Fossil Finders* elementary student mean scores improved on 5 of 7 items measuring *knowledge of the nature of science*. Students demonstrated a more informed understanding of two critical concepts, including (a) the tentative nature of science and (b) the use of creativity and imagination in scientific investigations. Interestingly, students were not able to articulate an informed definition of science in response to the question, "What is science?" either before or after exposure to the *Fossil Finders* materials.

We had evidence that elementary-level students in the Fossil Finders project classrooms gained a more informed understanding of one aspect of nature of science, that of scientists' use of creativity and imagination. In answering the question, why do scientists disagree about why and how dinosaurs died *(Q5)*, refer to Fig. 3.2 for a display of a one student's matched pre- and postquestionnaire responses to this item and see examples used in the scoring of the pre- and postresponses. In the preresponse, this student views science as basically a collection of facts. In the postresponse, this student indicates that in this kind of science (paleontology), one can never really know "because they don't have a time machine to go back in time."

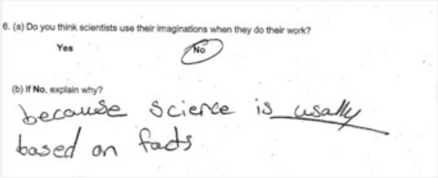
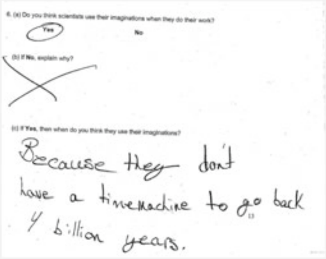
Pre	Post
 6. (a) Do you think scientists use their imaginations when they do their work? Yes [✓ No] (b) If **No**, explain why? because science is usally based on facts	 6. (a) Do you think scientists use their imaginations when they do their work? [✓ Yes] No (b) If **No**, explain why? (c) If **Yes**, then when do you think they use their imaginations? Because they don't have a timemachine to go back 4 billion years.
"They disagree because all facts have different senaroes [sic] unless you have all the facts so they might not have all the facts" (Scored as a 1)	"They disagree because they are different people." (Scored as a 3)

Fig. 3.2 Sample pre and post responses to VNOS – E Item 5

3.10 Conclusion

In this section, I return to the main question posed in this chapter, *how can we move science as inquiry into the classroom?* Preliminary findings from our recent project add support to the hypothesis, if there is an intense focus on *authenticity* during teacher professional development, this focus can strengthen a teacher's abilities to carry out inquiry-based instruction and facilitate students in learning science. This finding aligns with social constructivist and situated cognition theories of learning (Brown et al. 1989; Lave and Wenger 1991).

As we continue to work collaboratively with teachers and scientists to further develop and refine the Fossil Finders inquiry-based curriculum, we are working toward developing a model of an inquiry-based community of learners in a science classroom (Crawford et al. 2009). Our emerging model gives teachers specific roles; teachers not acting as passive participants in a professional development experience, but as active inquirers and agents of change. When our teachers are given opportunity to participate in authentic science, they demonstrate greater confidence in enacting inquiry-based instruction in their classrooms; their enthusiasm, in turn, increases, and we see evidence of motivated and engaged students in their classrooms.

Moving students toward an understanding and appreciation of the enterprise of science can enable the individual, regardless of race, culture, gender, and social class, to continue to build on his or her previous knowledge of science throughout life. In this way, a person may better participate as a citizen in understanding controversial and difficult issues, such as factors that may contribute to global climate change. The method of moving all learners toward a deeper understanding of science, first and foremost, positions students in active participation in authentic inquiry in education settings. When children engage in real-world, authentic investigations, connect their prior knowledge to new learning experiences, and are supported by a knowledgeable other in learning the cultural tools of science, they will gain a deeper understanding of science. The important point is that the teacher needs to hold, himself or herself, a well-developed view of what science is and of the pedagogy required for supporting children in their own thinking about science as inquiry.

In creating an authentic context that scaffolds children in pursuing answers to scientific questions, it is important that the questions have some importance to the life of the learner. Children have a good sense that "made-up" scientific questions, designed only for classroom use, are just that – prefabricated and decontextualized exercises that strive to teach scientific facts and procedures, with little regard for the nature of the learner. Authenticity to the learner does not necessarily mean that the topic is of cutting-edge importance to research scientists. The authentic science investigation may likely be embedded in a local community problem requiring a systematic approach for answering a question. The findings may not revolutionize the scientific world, but the experience *may* revolutionize the learner's thinking. An ultimate goal in science education is for the learner to reflect on his or her own learning, and it is this component of learning that will position the student in sustained curiosity and a lifelong quest for understanding science.

Acknowledgments I would like to extend my thanks to Dr. Daniel K. Capps, Dr. Maya Patel, and Dr. Xenia Meyer for their collaboration and wonderful insights into data analyses and conclusions, to Dr. Robert Ross and Dr. Warren Allmon of the Paleontological Research Institution in Ithaca, NY, for their continued collaboration, and to Dr. Sarah Woodruff of the Ohio's Evaluation and Assessment Center for Mathematics and Science Education and Discovery Center at Miami University, USA, for analyzing evaluation data and student assessments.

This chapter is based upon work supported by the National Science Foundation under Grant No. NSF 733233. Any opinions, findings, and conclusions or recommendations expressed in this chapter are those of the authors and do not necessarily reflect the views of The National Science Foundation.

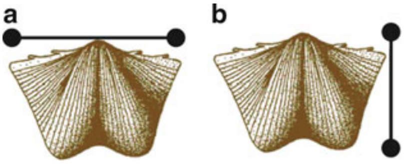
Appendix

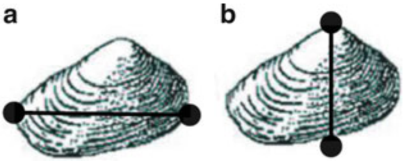
Lesson Description

This 5-day paleontological investigation engages students in authentic scientific inquiry. Through this investigation, there are many opportunities to discuss evolutionary, geological, and nature of science concepts. Students will learn about collecting, compiling, and interpreting data related to a population of fossils. After collecting the data, students will then enter their data into an online database and analyze and interpret the data they collected. The online database can also be used to share data with other classes and scientists and look for trends in the data beyond one's own class.

An Excerpt of the Lesson

- *Say*: We will be the first ones to collect this data. Nobody else has looked at these samples and knows what will be found! We will use this data to learn about science, share with scientists and other classes, and perhaps answer some questions of our own or questions posed by other classes.
- Explain how to fill out each sheet.
- For *brachiopods* and *bivalves* (sheets 1 and 2) students will measure in millimeters (mm's) in the *A* direction and *B* direction indicated on the handouts and PowerPoint slides (see example below). They will also indicate the color of the fossil and fragmentation.





- For all other organisms (sheets 3 and 4) the students need to first record what type of fossil they are measuring. Next they will measure length, width, color and fragmentation (see examples on the PowerPoint).

Data Analysis

Explain

The explanation portion of the investigation should take about 1–2 class periods but could take more if your students are engaged. The class should have already entered their data into the database. *Elementary grades* should focus on producing graphs from the first two data plots: *Relative Abundance of Organism within a Sample and Distribution of Organism Sizes*.

Within a sample of the database; however, feel free to use the other graphs as well. At the end of this section, elementary students will have recreated what proportions of different kinds of organisms would have lived in the Devonian Sea in the area they were studying. From this, they can begin to infer what the sea may have looked like based on the data they collected from their fossils.

(*Relative Abundance of Organisms within a Sample*) – If students have access to computers (or if there is a projector in the classroom), ask students to click on View Reports and create a graph showing relative abundance using the database. Have students use the graph they produce to consider how the *data they collected gives clues to what the area was like nearly 400 million years ago?* Students should select their sample from the drop-down list and click the graph button in the bottom-right hand corner of the box. Based on what they found in the rocks, what do they think the area where their rocks formed looked like during the Devonian Period (360 and 415 million of years ago)? What might it have been like if they snorkeled through the area? *What would the Devonian Sea have looked like ~400 million years ago? How do they know?*

References

American Association for the Advancement of Science. (1989). *Science for all Americans: A project 2061 report on literacy goals in science, mathematics and technology*. Washington, DC: Author.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.

Anderson, R. (2002). Reforming science teaching. What research says about inquiry? *Journal of Science Teacher Education, 13*(1), 1–12.

Bell, R., Blair, L., Crawford, B., & Lederman, N. (2003). Just do it? The impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching, 40*(5), 487–509.

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: The contribution of out-of-school learning. *International Journal of Science Education, 28*(12), 1373–1388.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Bybee, R., McCrae, B., & Laurie, R. (2009). PISA 2006: An assessment of scientific literacy. *Journal of Research in Science Teaching, 46*(8), 865–883.

Capps, D. K., & Crawford, B. A. (2010, March 20–24). *Teachers translating inquiry-based curriculum to the classroom following professional development: A pilot study*. A paper presented at the National Association of Research in Science Teaching Annual Conference, Philadelphia, PA.

Catley, K., Lehrer, R., & Reiser, B. (2004). *Tracing a perspective learning progression*. Paper commissioned by the National Academies Commission on Test Design on K-12 Science Achievement. Washington, DC: National Academy of Sciences.

Chinn, C. A., & Malholtra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175–219.

Crawford, B. A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*(9), 916–937.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching, 44*(4), 613–642.

Crawford, B. A., & Cullin, M. J. (2004). Supporting prospective teachers' conceptions of modelling in science. *International Journal of Science Education, 26*(11), 1379–1401.

Crawford, B. A., Krajcik, J. S., & Marx, R. W. (1999). Elements of a community of learners in a middle school science classroom. *Science Education, 83*(6), 701–723.

Crawford, B. A., Zembal-Saul, C., Munford, D., & Friedrichsen, P. (2005). Confronting prospective teachers' ideas of evolution and scientific inquiry using technology and inquiry-based tasks. *Journal of Research in Science Teaching, 42*(6), 613–637.

Crawford, B. A., Capps, D., Meyer, X., Ortenzi, D., & Ross, R. (2009, April 17–21). *Closing the circle of authentic scientific research and inquiry-based pedagogy: Teachers, scientists, and science educators in a community of learners*. A poster presented at the National Association of Research in Science Teaching (NARST) 2009, Garden Grove, CA.

Creswell, J. W. (1998). *Qualitative inquiry and research design*. Thousand Oaks, CA: Sage Publishers.

Dewey, J. (1938). *Experience and education*. New York: Collier.

Driver, R. (1989). The construction of scientific knowledge in school classrooms. In R. Millar (Ed.), *Doing science: Images of science in science education* (pp. 126–136). London: The Falmer Press.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 4.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8.* Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Gallagher, J. J. (1991). Prospective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. *Science Education, 75*(1), 121–133.

Hodson, D. (1998). Is this really what scientists do? Seeking a more authentic science in and beyond the school laboratory. In J. Wellington (Ed.), *Practical work in school science: Which way now?* (pp. 93–108). London: Routledge.

Krajcik, J. S., Mamlok, R., & Hug, B. (2000). Modern content and the enterprise of science: Science education in the twentieth century. In L. Como (Ed.), *Education across a century: The centennial volume. One-hundredth yearbook of the national society for the study of education* (pp. 205–238). Chicago: University of Chicago Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press.

Lederman, N. G. (1992). Students and teachers conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331–359.

Lederman, J. S., & Lederman, N. G. (2005). *Developing and assessing elementary teachers' and students' understandings of nature of science and scientific inquiry*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Dallas, TX.

Loucks-Horsley, S., Hewson, P. W., Love, N., & Stiles, K. E. (2003). *Designing professional development for teachers of science and mathematics* (2nd ed.). Thousand Oaks: Corwin Press.

Luft, J. A. (2001). Changing inquiry practices and beliefs: the impact of an inquiry-based professional development programme on beginning and experienced secondary science teachers. *International Journal of Science Education, 23*(5), 517–534.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage Publishers.

Millar, R. (1989). Bending the evidence: The relationship between theory and experiment in science education. In R. Millar (Ed.), *Doing science: Images of science in science education* (pp. 126–136). London: The Falmer Press.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

Rahm, J., Miller, H., Hartley, L., & Moore, J. C. (2003). The value of an emergent notion of authenticity: Examples from two student/teacher–scientist partnership programs. *Journal of Research in Science Teaching, 40*(8), 737–756.

Rosebery, A. S., Warren, B., & Conant, F. R. (1989). *Cheche konnon: Science and literacy in language minority classrooms* (BBN Technical Report No. 7305). Cambridge, MA: BBN Laboratories, Inc.

Roth, W. M. (1995). *Authentic school science: Knowing and learning in open-inquiry science laboratories*. Dordrecht: Kluwer.

Schwartz, R., & Crawford, B. A. (2004). Authentic scientific inquiry as a context for teaching nature of science: Identifying critical elements for success. In L. Flick & N. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 331–355). Dordrecht: Kluwer Publishing Co.

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education, 88*(4), 610–645.

Vygotsky, L. S. (1978) *Mind in society: The development of higher psychological processes* (M. Cole, V. John-Steiner, S. Scriber, & E Souberman Eds., and Trans.). Cambridge, MA: Harvard University Press.

Woodruff, S. B., Morio, K. L., & Li, Y. (2011). *Evaluation of fossil finders, using fossils to teach about evolution, inquiry, and nature of science: Annual report 2009–2010*. Oxford: Miami University, Ohio's Evaluation & Assessment Center for Mathematics and Science Education.

Chapter 4
Conceptual Change: Still a Powerful Framework for Improving the Practice of Science Instruction

Reinders H. Duit and David F. Treagust

4.1 Introductory Remarks

This is a position paper that draws on recent, more elaborated reviews of the state of conceptual change conceptions in science education research. The first review was written for a handbook on conceptual change (Duit et al. 2008). The second review appeared in a special issue of the journal *Cultural Studies of Science Education* (Treagust and Duit 2008a). This special issue includes two papers attempting to outline major features of the state of research concerning conceptual change (our paper) and social cultural studies (Roth et al. 2008). Both papers are commented by authors from the social cultural studies camp (our paper) and by conceptual change-oriented authors (the paper by Roth et al.). Our response to the comments further clarifies the conceptual change view we hold (Treagust and Duit 2008b). In the following, we will summarize our views that are more fully outlined in the mentioned documents.

R.H. Duit (✉)
Leibniz-Institute for Science and Mathematics Education (IPN),
University of Kiel, Kiel, Germany
e-mail: RDuit@t-online.de

D.F. Treagust
Science and Mathematics Education Centre, Curtin University of Technology, Perth, Australia

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_4,

4.2 Theoretical Developments in the Area of Conceptual Change

4.2.1 Students' Conceptions: Towards Multiple Conceptual Changes

Students may come to science classes with pre-instructional conceptions and ideas about the phenomena and concepts to be learned that are not in harmony with science views. Furthermore, these conceptions and ideas are firmly held and are often resistant to change. Initially, research in the 1970s focused on conceptions on the content level. Whilst such studies continue to be produced, investigations of students' conceptions at meta-levels, namely, conceptions of the nature of science and science processes (McComas 1998; Lederman 2007) as well as meta-cognitive views of learning (Baird and Mitchell 1986), have been given attention only in the late 1980s and 1990s. It turned out that usually multiple conceptual changes of all three aspects are necessary.

As the term 'conceptual *change*' invites several misunderstandings, it is necessary to point out that in 'mainstream' conceptual change research, this term has not been interpreted as 'exchange' of ideas. Research has clearly shown that a simple exchange of students' pre-instructional ('alternative') conceptions is not possible: 'Conceptual change is considered not as a replacement of an incorrect naïve theory with a correct theory but rather, as an opening up of conceptual space through increased meta-conceptual awareness and epistemological sophistication, creating the possibility of entertaining different perspectives and different point of views' (Vosniadou 2008).

4.2.2 Teachers' Conceptions: A Major Obstacle for Efficient Teaching

Research starting in the 1980s has shown that many teachers hold conceptions of science concepts that are not in accordance with the science view and often are similar to students' pre-instructional conceptions. It became also evident that many teachers hold limited views of the teaching and learning process as well of the nature of science and science processes (Duit 2009; Duit et al. 2008). Hence, teachers' conceptions of various kinds also need to undergo conceptual changes. Basically, the same conceptual change frameworks for addressing students' conceptions have proven valuable to develop teachers' conceptions (Hewson et al. 1999). To further develop and hence change teachers' conceptions of various kinds is generally seen as a major issue in attempting to improve instructional practice (Anderson and Helms 2001; Borko 2004; Abell 2007).

4.2.3 The 'Classical' Conceptual Change Approach

Research on the role of students' pre-instructional ('alternative') conceptions in learning science developed in the 1970s primarily draws on two theoretical perspectives (Driver and Easley 1978): Ausubel's (1968) dictum that the most important single factor influencing learning is what the learner already knows and on Piaget's idea of the interplay of assimilation and accommodation. The 'classical' conceptual change approach introduced by Posner et al. (1982), which may be briefly characterized by the quadriga of 'dissatisfaction, intelligibility, plausibility and fruitfulness', draws on Toulmin's metaphor of conceptual ecology, T. S. Kuhn's view of revolutionary and evolutionary changes of concepts in the history of science and also on Piaget's terms, assimilation and accommodation. The 'classical' approach clearly has been the most influential perspective in the domain of conceptual change. However, it has been further developed in various ways as will be outlined below.

4.2.4 Affective Variables

The 'classical' conceptual change approach – at least implicitly – includes affective variables as influential factors (moderating variables) in facilitating conceptual change. Pintrich et al. (1993), therefore, overstated matters when accusing the classical approach being primarily or even totally cognitively oriented. They explicitly argued that affective variables are essential in fostering conceptual change. Drawing on their seminal paper, the role of affective variables was more fully investigated in the 1990s (e.g. Tyson et al. 1997). Usually, however, affective variables were primarily seen as variables needed to support conceptual change. But it appears that neglected affective variables such as interest or self-concept have to be deliberately developed during instruction, so these variables also have to undergo conceptual change. In other words, affective variables like interest need to be developed through notions of intelligibility, plausibility and fruitfulness in order to be realized. More recently, Zembylas (2005), who argues for the necessity of linking cognitive and emotional variables of science learning, sees both variables of equal status in the learning process. However, the kinds of linking that are needed are still not clear. Further work, both theoretically and empirically, is needed.

4.2.5 Constructivist Views and Conceptual Change

Conceptual change perspectives are closely linked to constructivist epistemological views. More recently, we witnessed a development of constructivist views from initially (in the 1980s) radical constructivist views focusing on the construction of the individuals towards multi-perspective constructivist views (Taber 2006). These views include features of radical constructivism and social constructivist (as well as social cultural) origins (Phillips 2000). More recent conceptual change views often are embedded in such multi-perspective constructivist views – or at least should be based on these views. However, more work is also needed here, for example, in which way the epistemologically different perspectives may be linked needs further theoretical considerations. So far, there is still a certain danger that a mere patchwork of epistemological perspectives is applied. It also has to be further investigated what it means that perspectives are complementary. The previously mentioned special issue of the journal *Cultural Studies in Science Education* may be seen as an attempt to address such questions (Tobin 2008).

4.2.6 Towards More Inclusive Conceptual Change Views

The development of conceptual change views from the early 1980s to the present state may be characterized as a progression towards more inclusive views. On the one hand, these more recent views allow addressing the dynamics of teaching and learning processes more comprehensively than the initial views (like the 'classical' view). However, the theoretical frameworks have become more and more complicated and may cause serious problems for teachers using them in regular classrooms as will be argued below.

4.3 Efficiency of Conceptual Change-Oriented Instructional Design

Usually, researchers who use a conceptual change approach in their classroom-based studies report that their approach is more efficient than traditional ones. Efficiency concerns predominantly cognitive outcomes of instruction. The development of affective variables during instruction is often not viewed as the outcome per se. Only more recent multi-dimensional conceptual change perspectives as outlined above consider both cognitive and affective outcomes (Tyson et al. 1997; Zembylas 2005). With regard to cognitive outcomes, there appears to be ample evidence in various studies now that these approaches are more efficient than traditional approaches dominated by transmissive views of teaching and learning. This seems to be the case in particular if more inclusive conceptual change approaches based on multi-dimensional perspectives are employed (Duit et al. 2008). Recent large-scale programmes to improve the quality of science instruction include instructional methods that are clearly oriented towards constructivist conceptual change approaches (Beeth et al. 2003; Ostermeier et al. 2010). A large spectrum of conceptual change-oriented instructional methods has been developed the past decades (Widodo 2004). Particular attention was given to cognitive conflict. Cognitive conflict plays a major role in Piagetian approaches such as the ‘learning cycle’ (Lawson et al. 1989) but also in ‘constructivist teaching sequences’ (Driver 1989). Research has shown, however, that much care is needed if cognitive conflict strategies are used for facilitating conceptual change. It is not only necessary to carefully ensure that students experience the conflict but also consider the role of specific, usually small scale, sudden insights within the long-lasting gradual process of conceptual change (Vosniadou and Ioannides 1998).

4.4 Embedding Conceptual Change into Models of Instructional Planning

Beeth et al. (2003) argue that the following three characteristics of quality development approaches are essential for improving instruction: (1) supporting teachers to rethink the representation of science in the curriculum; (2) enlarging the repertoire of tasks, experiments and teaching and learning strategies and resources; and (3) promoting strategies and resources that attempt to increase students’ engagement and interests. They claim that not only conceptual change-based instructional methods need to be introduced in order to improve teaching and learning of science but that also the traditional science content structure needs to be changed. The term *content structure* includes the particular content elements and the relations of these elements. The content structure *for* instruction needs to be designed taking into account the actual knowledge of what we know about students’ pre-instructional conceptions and learning processes from conceptual change studies. Interestingly, this issue seems to be neglected or given only little attention in many studies on conceptual change. However, it seems to be essential to embed studies of conceptual change in models of instructional planning that deliberately take into account the aims of instruction and the student cognitive and affective perspectives when planning content structure for instruction. It seems that the *Model of Educational Reconstruction* (Duit et al. 2005b; Duit et al. 2012) provides such a theoretical frame. Within the framework of the model, the following three tasks are intimately linked: (1) clarification and analysis of science subject matter (e.g. in the field of evolution, energy or combustion), (2) taking into account student perspectives (cognitive and affective) with regard to the phenomena and (3) design of learning environments that deliberately support student learning processes.

4.5 Conceptual Change and Instructional Practice

It seems that conceptual change ideas so far do not inform practice to a considerable extent. Anderson and Helms (2001) argue that teachers usually are not well informed about the recent state of research on teaching and learning and hold views that are predominantly transmissive. This is true not only for the domain of science education but also for the individual professional development of teachers in other domains such as mathematics (Borko 2004). Some studies providing information on teachers' views about teaching and learning also include findings on teachers' ways of teaching (Anderson and Helms 2001; Jones and Carter 2007). Lyons (2006, p. 595) summarizes interpretive studies on students' experiences in Sweden, England and Australia in stating: 'Students in the three studies frequently described school pedagogy as the transmission of content expert sources – teachers and texts – to relative passive recipients'. Video studies on the practice of substantially large samples of teachers in science and mathematics revealed basically the same findings. The seminal TIMSS Video Study on Mathematics Teaching (Stigler et al. 1999) compared the practice of mathematics instruction in the United States, Japan and Germany. Instruction was observed to be primarily teacher-oriented, and instructional scripts based on transmissive views of teaching and learning predominated. The TIMSS Video Study on Science Teaching (Roth et al. 2006) investigated instructional scripts in Australia, the Czech Republic, Japan, the Netherlands and the United States. Again, the predominating impression was instructional scripts informed by traditional transmissive views of teaching and learning. However, instructional features oriented towards constructivist conceptual change perspectives, though not frequent, did occur in both studies to different degrees in the participating countries.

A video study on the practice of German and Swiss lower secondary physics instruction also revealed basically similar predominating instructional scripts (Duit et al. 2005a; Seidel et al. 2005). As part of a pilot study, Widodo (2004) investigated teachers' instructional behaviour explicitly from constructivist perspectives and also analysed to what degree the practice could be seen as informed by conceptual change views of teaching and learning. Analysis of the data gained in these studies showed that most teachers are not well informed about key ideas of conceptual change research. Further, their views about their students' learning usually are not consistent with the state of recent theories of teaching and learning. Many teachers appear to lack an explicit view of student learning. Considerations about the content to be taught predominate teacher planning. Reflections about students' perspectives and their role in the learning process play a comparably minor role (Duit et al. 2007).

4.6 Conceptual Change and Teacher Professional Development

As briefly mentioned previously, investigating teachers' views of teaching and learning science and the means to improve teachers' views and their instructional behaviour through teacher professional development have developed into a research domain that has been given much attention since the late 1990s (Borko 2004; Harrison et al. 2008; Abell 2007). Two major issues are addressed in these teacher professional development projects. First, teachers are made familiar with research knowledge on teaching and learning by being introduced to recent constructivist and conceptual change views and are introduced to instructional designs that are oriented towards these views. Second, how teachers link their own content knowledge and their pedagogical knowledge is an essential aspect of this process; only when teachers can effectively relate these two knowledge bases will constructivist and conceptual change views be implemented in an effective manner (van Driel et al. 1998; West and Staub 2003).

Consequently, the process of teacher professional development can be viewed as a set of substantial conceptual changes that teachers have to undergo. Learning to teach for conceptual change means ‘that teachers must undergo a process of pedagogical changes themselves’ (Stofflett 1994, p. 787). The conceptual change perspectives developed to analyse and improve student learning have also proven to be the basis of a valuable framework for teacher learning (Hewson et al. 1999).

4.7 Challenges for Future Research and Development

Research on conceptual change in science offers several challenges for the furthering of this field of scientific and educational endeavour. These challenges are (a) conceptual – with the need to consider the usefulness of the term conceptual change, (b) theoretical – with the need to examine conceptual change from multiple perspectives, (c) methodological – with the need to determine the necessary and sufficient evidence for identifying conceptual change and (d) universally practicality – with the need to bring successful conceptual change teaching approaches to normal classrooms.

Challenge 1. *Is conceptual change still an adequate term to indicate its actual meaning?*

The above overview of the development of theoretical conceptual change perspectives shows that conceptual change has grown to one of the leading paradigms in research on teaching and learning. It is interesting to see a continuous progress since early conceptual change research occurred and to realize that the definition of what changes in conceptual change has revised substantially over the past three decades (Duit et al. 2008). Initially, the term change was frequently used in a somewhat naïve way – if seen from the inclusive perspectives that have since developed. The term conceptual change was even frequently misunderstood as exchange of the students’ pre-instructional (or alternative) views for the science view. The meaning of change in the ‘classical’ conceptual change view (Posner et al. 1982), however, is somewhat far from the actual predominating view outlined, for instance, by Vosniadou and Ioannides (1998). They claimed that learning science should be viewed as a ‘gradual process during which initial conceptual structures based on children’s interpretation of everyday experience are continuously enriched and restructured’ (p. 1213).

Taking into account that misunderstandings of the term conceptual change may be invited by various meanings of change in everyday language and considering the substantial changes of the initial meaning of conceptual change, it may be timely to replace that term. We agree with Kattmann (2007) that his term ‘conceptual reconstruction’ more appropriately indicates the actual meaning predominating as outlined above, and we recommend the use of this latter term be considered in future to indicate conceptual learning (Treagust and Duit 2008b).

Challenge 2. *Research on conceptual change needs to take into account multiple perspectives, including knowledge of the essential defining elements of the theoretical frame and affective variables.*

As outlined above, the state of theory building on conceptual change has become more and more sophisticated, and the teaching and learning strategies developed have become more and more complex over the past 30 years (see also Limon and Mason 2002 as well as Sinatra and Pintrich 2003). Whilst these developments are necessary in order to address the complex phenomena of teaching and learning science more and more adequately, several demands are affiliated with these achievements:

(a) On the theoretical plane: As briefly outlined above, it is necessary to further investigate in which way the various theoretical perspectives brought together are linked and may constructively interact in a complementary way.
(b) Particular attention has to be given to the more recent notion that instruction should give cognitive and affective outcomes equal attention, that is, both have to be developed.
(c) On the empirical plane: Research methods applied need to address the various perspectives (see below).
(d) On the plane of improving instructional practice: Multiple perspectives are particularly demanding for the teachers who have to transfer the findings into practice (see below).

In a nutshell, research on conceptual change has developed to a rich and significant domain of educational research since the 1970s. The theoretical frameworks and research methods developed allow fine-grained analyses of teaching and learning processes. The findings of research provide powerful guidance for the development of instructional design for science education that societies need. However, various demands still need to be addressed.

Challenge 3. *Conceptual change approaches of teaching and learning science need to be embedded in more inclusive models of instructional planning.*

The focus of many studies in the field of conceptual change is primarily on improving the way science is taught. Conceptual change denotes, in most studies, developing student pre-instructional ideas towards the science point of view by conceptual change-oriented instructional methods. However, it is necessary to give equal attention to traditional science content structures for instruction from the perspectives of the aims of instruction and the learners (Fensham 2001). In other words, it is essential to embed conceptual change approaches into models of instructional planning that take into account the intimate interaction of all components of instruction, namely, the aims of instruction, the structure of the science content taught in instruction, the instructional methods employed and students’ prior knowledge as well as their interests and self-concepts. In many conceptual change studies, such an inclusive theoretical frame is not explicitly taken into account. Hence, it is necessary to further develop existing models like the *Model of Educational Reconstruction* (Duit et al. 2012).

Challenge 4*. Determine the necessary and sufficient evidence for identifying conceptual change.*

Typically, researchers of students' conceptual change collect data from written tests, interviews and, less frequently, think-aloud protocols. However, reports of conceptual change often simply refer to changes in concepts, such as on a test, without any identification of the learning processes that have taken place. In addition, it is often the case that more than one source of evidence – for example, classroom observations of a students' discussion with the teacher in addition to interviews – is needed to judge conceptual change. Even when a theoretical framework is clearly enunciated, there are often different interpretations of the data, and oftentimes these decisions are not unambiguous.

Research as outlined in the first lines of the above paragraph is often quite near the 'classical' conceptual change perspective. As has been argued, multi-perspective views are needed in order to address the complexity of teaching and learning processes more adequately. Therefore, a wider spectrum of research methods is necessary, for example, including variants of learning process studies with a certain focus on discourse analyses. In other words, mixed method studies including quantitative and qualitative data have to be further developed and applied.

Challenge 5*. Bring successful conceptual change teaching approaches to normal classrooms.*

Successful teaching that has outcomes of students' conceptual change is perhaps the major challenge for researchers working in the field of conceptual change. As outlined above, a major contributing factor to the lack of successful implementation of conceptual change approaches to teaching in normal classrooms is that teachers usually are not well informed about actual views of efficient teaching and learning available from the research community. Most teachers hold views that are limited if seen from the recent inclusive conceptual change perspectives. Further, instructional practice is also usually far from a practice that is informed by conceptual change perspectives. Taking into account science teachers' deeply rooted views of what they perceive as good instruction, it becomes apparent that various closely linked conceptual changes on the teachers' beliefs about teaching and learning are necessary to commence and set recent conceptual change views into practice. Consequently, it appears that the gap between what is necessary from the researchers' perspective and what may be set into practice by normal teachers has increased. In order to bridge the gap between the researchers' and teachers' perceptions of conceptual change, it is necessary to describe how opportunities for conceptual change can be built on existing teachers' instructional strategies.

Interestingly, the frameworks of student conceptual change – being predominantly researched so far – may also provide powerful frameworks for teacher change towards employing conceptual change ideas. There are attempts to use this potential as discussed above. However, more research in this field based on the recent inclusive conceptual change perspectives is most desirable.

An additional demand seems to be that closer cooperation of various groups working to improve instructional practice is needed. On the one hand, it seems that more recent conceptual change perspectives seriously consider the necessity of improving student scientific literacy and research findings available provide valuable instructional methods to improve scientific literacy (Duit et al. 2008, pp. 636–637). On the other hand, the major 'quality development' programmes draw on instructional methods proposed by conceptual change research (Beeth et al. 2003; Ostermeier et al. 2010). It is also most pleasing that such 'conceptual change-oriented' methods have proven to be more efficient than more traditional methods (e.g. Schroeder et al. 2007). However, closer cooperation between teachers and researchers may allow better use of the still limited research and development sources for improving practice.

Finally, we would like to point out that research on instructional quality has shown that usually a single instructional method (like addressing students' pre-instructional conceptions) does not lead to better outcomes per se. Quality of instruction is always due to a certain orchestration (Oser and Baeriswyl 2001) of various instructional methods and strategies. Hence, conceptual change strategies may only be efficient if they are embedded in a conceptual change supporting learning environment that includes many additional features such as specially organized instruction based on models of teaching.

References

Abell, S. (2007). Research on science teacher knowledge. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1165). Mahwah: Erlbaum.

Anderson, R. D., & Helms, J. V. (2001). The ideal of standards and the reality of schools: Needed research. *Journal of Research in Science Teaching, 38*(1), 3–16.

Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart and Winston.

Baird, J. R., & Mitchell, I. J. (1986). *Improving the quality of teaching and learning – An Australian case study*. Melbourne: The Monash University Printery.

Beeth, M., Duit, R., Prenzel, M., Ostermeier, C., Tytler, R., & Wickman, P. O. (2003). Quality development projects in science education. In D. Psillos, P. Kariotoglou, V. Tselfes, G. Fassoulopoulos, E. Hatzikraniotis, & M. Kallery (Eds.), *Science education research in the knowledge based society* (pp. 447–457). Dordrecht: Kluwer Academic Publishers.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15.

Driver, R. (1989). Changing conceptions. In P. Adey, J. Bliss, J. Head, & M. Shayer (Eds.), *Adolescent development and school science* (pp. 79–104). London: The Falmer Press.

Driver, R., & Easley, J. A. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5*, 61–84.

Duit, R. (2009). *STCSE – Bibliography: Students' and teachers' conceptions and science education.* Kiel: IPN – Leibniz Institute for Science and Mathematics Education. http://www.ipn.uni-kiel.de/aktuell/stcse/stcse.html. Accessed 1 March 2012.

Duit, R., Fischer, H., Labudde, P., Brückmann, M., Gerber, B., Kauertz, A., Knierim, B., & Tesch, M. (2005a). Potential of video studies in research on teaching and learning science. In R. Pintó & D. Couso (Eds.), *Proceedings of the Fifth International ESERA Conference on Contributions of Research to Enhancing Students' Interests in Learning Science* (pp. 829–842). Barcelona: UAB.

Duit, R., Gropengießer, H., & Kattmann, U. (2005b). Towards science education research that is relevant for improving practice: The model of educational reconstruction. In H. Fischer (Ed.), *Developing standards in research on science education* (pp. 1–9). London: Taylor & Francis.

Duit, R., Widodo, A., & Wodzinski, C. T. (2007). Conceptual change ideas – Teachers' views and their instructional practice. In S. Vosniadou, A. Baltas, & X. Vamvokoussi (Eds.), *Reframing the problem of conceptual change in learning and instruction* (Advances in learning and instruction series, pp. 197–217). Amsterdam: Elsevier.

Duit, R., Treagust, D., & Widodo, A. (2008). Teaching for conceptual change – Theory and practice. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 629–646). Mahwah: Lawrence Erlbaum.

Duit, R., Gropengießer, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The Model of Educational Reconstruction – A framework for improving teaching and learning science. In D. Jorde & J. Dillon (Eds.), *The World of Science Education: Science education research and practice in Europe* (pp. 13–37). Rotterdam: Sense Publishers.

Fensham, P. (2001). Science content as problematic – Issues of research. In H. Behrendt et al. (Eds.), *Research in science education – Past, present, and future* (pp. 27–41). Dordrecht: Kluwer Academic Publishers.

Harrison, C., Hofstein, A., Eylon, B. S., & Simon, S. (2008). Evidence-based professional development in two countries. *International Journal of Science Education, 30*(5), 577–591.

Hewson, P. W., Tabachnick, B. R., Zeichner, K. M., Blomker, K. B., Meyer, H., Lemberger, J., Marion, R., Park, H.-J., & Toolin, R. (1999). Educating prospective teachers of biology: Introduction and research methods. *Science Education, 83*(3), 247–273.

Jones, M. G., & Carter, G. (2007). Science teachers' attitudes and beliefs. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 1067–1104). Mahwah: Erlbaum.

Kattmann, U. (2007). Learning biology by means of anthropomorphic conceptions? In M. Hamman et al. (Eds.), *Biology in context: Learning and teaching for 21st century* (pp. 21–26). London: Institute of Education, University of London.

Lawson, A. E., Abraham, M., & Renner, J. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills (NARST monograph number one)*. Cincinnati: National Association for Research in Science Teaching/University of Cincinnati.

Lederman, N. (2007). Nature of science: Past, present, and future. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 831–879). Mahwah: Erlbaum.

Limon, M., & Mason, L. (2002). *Reconsidering conceptual change: Issues in theory and practice*. Dordrecht: Kluwer Academic Publishers.

Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education, 28*(6), 591–613.

McComas, W. (Ed.). (1998). *The nature of science in science education – Rationales and strategies*. Dordrecht: Kluwer Academic Publishers.

Oser, F. K., & Baeriswyl, F. J. (2001). Choreographies of teaching: Bridging instruction to learning. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed., pp. 1031–1065). Washington, DC: American Educational Research Association.

Ostermeier, C., Prenzel, M., & Duit, R. (2010). Improving science and mathematics instruction – The SINUS-Project as an example for reform as teacher professional development. *International Journal of Science Education, 32*(3), 303–327.

Phillips, D. C. (2000). *Constructivism in education: Opinions and second opinions on controversial issues*. Chicago: The National Society for the Study of Education.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63*(2), 167–199.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.

Roth, K., Druker, S., Garnier, H., Chen, C., Kawanaka, T., Rasmussen, D., Trubacova, S., Warvi, D., Okamoto, Y., Gonzales, P., Stigler, J., & Gallimore, R. (2006). *Teaching science in five* *countries: Results from the TIMSS 1999 videostudy. Statistical analysis report*. Washington, DC: NCES – National Centre for Educational Statistics.

Roth, W. M., Lee, Y. J., & Hwang, S. W. (2008). Culturing conceptions: From first principles. *Cultural Studies of Science Education, 3*(2), 231–261.

Schroeder, C. M., Scott, T. P., Tolson, H., Huang, T. Y., & Lee, Y.-H. (2007). A meta-analysis of national research: Effects of teaching on student achievement in the United States. *Journal of Research in Science Teaching, 44*(10), 1436–1460.

Seidel, T., Rimmele, R., & Prenzel, M. (2005). Clarity and coherence of lesson goals as a scaffold for student learning. *Learning and Instruction, 15*(6), 539–556.

Sinatra, G. M., & Pintrich, P. R. (2003). *Intentional conceptual change*. Mahwah: Erlbaum.

Stigler, J. W., Gonzales, P., Kawanaka, T., Knoll, S., & Serrano, A. (1999). *The TIMSS videotape classroom study. Methods and findings from an exploratory research project on eighth-grade mathematics instruction in Germany, Japan and the United States.* Washington, DC: U.S. Department of Education.

Stofflett, R. T. (1994). The accommodation of science pedagogical knowledge: The application of conceptual change constructs to teacher education. *Journal of Research in Science Teaching, 31*(8), 787–810.

Taber, K. S. (2006). Beyond constructivism: The progressive research programme into learning science. *Studies in Science Education, 42*(1), 125–184.

Tobin, K. (2008). In search of new lights: Getting the most from competing perspectives. *Cultural Studies of Science Education, 3*(2), 227–230.

Treagust, D., & Duit, R. (2008a). Conceptual change: A discussion of theoretical, methodological and practical challenges for science education. *Cultural Studies of Science Education, 3*(8), 297–328.

Treagust, D., & Duit, R. (2008b). Compatibility between cultural studies and conceptual change in science education: There is more to acknowledge than to fight straw men. *Cultural Studies of Science Education, 3*(2), 387–395.

Tyson, L. M., Venville, G. J., Harrison, A. G., & Treagust, D. F. (1997). A multidimensional framework for interpreting conceptual change in the classroom. *Science Education, 81*(4), 387–404.

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673–696.

Vosniadou, S. (2008). Bridging culture with cognition: A commentary on 'culturing conceptions: From first principles' by Roth, Lee and Hwang. *Cultural Studies of Science Education, 3*(2), 277–282.

Vosniadou, S., & Ioannides, C. (1998). From conceptual change to science education: A psychological point of view. *International Journal of Science Education, 20*(12), 1213–1230.

West, L., & Staub, F. C. (2003). *Content-focused coaching: Transforming mathematics lessons*. Portsmouth/Pittsburgh: Heinemann/University of Pittsburgh.

Widodo, A. (2004). *Constructivist oriented lessons: The learning environment and the teaching sequences*. Frankfurt: Peter Lang.

Zembylas, M. (2005). Three perspectives on linking the cognitive and the emotional in science learning: Conceptual change, socio-constructivism and poststructuralism. *Studies in Science Education, 41*(1), 91–116.

Chapter 5
Multimodality in Problem Solving

Shien Chue and Kim Chwee Daniel Tan

5.1 Introduction

Problem solving in chemistry education has constantly intrigued researchers (Bennett 2008; Bowen and Bodner 1991; Chandrasegaran et al. 2009; Gabel and Bunce 1994; Krajcik 1991; Tsaparlis and Angelopoulos 2000). In the past, problem solving in chemistry focused on how students might follow the procedural steps of understanding the problem, devising a plan, carrying out the plan, and reflecting upon the actions taken (Bodner and Pardue 1995). While such research had resulted in new knowledge of how students solve problems through a more cyclical approach with the use of symbols and diagrams for visual representation of the problem (Lee and Fensham 1996), a deeper examination of the interactions between the problem solvers and the given task is required (Bodner and Herron 2002). Research on problem solving in organic chemistry mostly focuses on students' cognitive processes during problem solving (Bhattacharyya 2004; Stieff 2007; Tsaparlis and Angelopoulos 2000; Zoller and Pushkin 2007). Often, research reiterate claims that students solve chemistry problems using algorithmic methods and lack understanding of chemical concepts on which the problems were based (Gabel et al. 2006).

Research is beginning to suggest that the use of multiple representations play an important role in helping students construct and communicate chemistry knowledge

---

S. Chue (✉)
Centre for Research in Pedagogy and Practice, National Insitute of Education,
Nanyang Technological University, Singapore
e-mail: ruikyi@yahoo.com

K.C.D. Tan
Natural Sciences and Science Education, National Institute of Education,
Nanyang Technological University, Singapore
e-mail: daniel.tan@nie.edu.sg

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_5,

(Hand and Choi 2010; Nakhleh and Postek 2008; Yore and Treagust 2006). Recent studies on students' learning of organic chemistry (Anderson and Bodner 2008; Bhattacharyya and Bodner 2005) highlight differences in how teachers and students use chemical symbols and structures for communicating chemistry knowledge. It appears that students have difficulty in representing chemical phenomenon using chemical symbols as well as in developing explanations of chemistry reaction mechanisms.

However, there has been less focus on students' use of multiple modal representations as they engage with problem-solving tasks in the context of organic chemistry. While researchers highlight the importance of mental models in the development of problem-solving capabilities (Bodner and Domin 2000; McLoughlin and Taji 2005), much remains to be elaborated about how students can engage in successful problem solving through creation of appropriate representations. Similarly, while graduate students use different representational forms such as verbal and pictorial representations as a common language for communicating scientific information to others (Bowen 1990), little is known if science undergraduates do the same (Bodner and Weaver 2008).

5.2 Multimodality

A multimodal social semiotics epistemology (Kress 2003; Kress et al. 2001) offers a useful way to examine organic chemistry problem solving. The basic concept of multimodality positions knowledge as coconstructed through the coordination of meaning-making resources that is not limited to only language. Language is the primary medium for reasoning and conceptualization in science as well as reporting and persuading others about these claims (Lemke 1998). Without language in the forms of oral, visual, and print, social practices of engagement in knowledge construction are not possible (Norris and Phillips 2003), and this is supported by a study of the coauthorship process in research laboratories where the quality of writing and science produced by novice scientists improved after reiterative process of writing and reviewing with other members of the scientific community (Florence and Yore 2004). Extending beyond speech or writing, semiotic resources such as visuals and even actions are capable of carrying information that contributes to the overall meaning that one intends to communicate. By attending to all modes of communication as part of meaning making, the monolithic emphasis on language as the valued mode of communication in education is superseded by a growing recognition of the multiple modes in which ideas could be represented (Bezemer and Kress 2008; Knain 2006; Kress et al. 2000, 2001).

In science education, a myriad of representations and artifacts are required to represent scientific concepts in addition to speech or writing. These multiple modes of representations are material expressions of abstract scientific phenomenon being experienced and can be understood as individuals' articulations of their observations and knowledge about phenomena (Lemke 2001). For example, it was found that teachers seek to shape students' understanding of the particulate nature of matter through the use of actions, speech, and diagrams (Kress et al. 2001) to provide students with the visualization of abstract notions of particulate interactions. Likewise, undergraduate physics students were found to rely on the affordances of different semiotic resources in representing abstract knowledge for learning (Airey and Linder 2009). For instance, to understand energy transfer, students need to be fluent with definitions of the various types of energy and use and apply mathematical equations as well as graphical representations for quantifications of energy. They also need to engage in physics experiments to experience the abstract concepts in the real-world context. Similarly, learning chemistry requires students to describe chemical reactions textually, graphically, or even with a combination of both in order to translate between multiple dimensional molecular representations of chemical structures (Dori and Barak 2001).

Therefore, ideas about multimodality can be useful in describing and examining problem solving in a semantically rich field such as organic synthesis. This is accomplished by first positioning visual inscriptions, gestures, and speech as common semiotic resources and layering a dynamic view on how the resources are employed for meaning making. While research has established the social and cognitive affordances of multiple representations (Kozma 2003; Schank and Kozma 2002), little research actually foregrounds students as members of the scientific community engaged with multiple representations for problem solving in chemistry. Hence, the purpose of this study is to shed light on how students express themselves within the problem-solving context through the coordination of multiple semiotic resources that reveals scientific knowledge through time.

5.3 The Study

In this study, we examine a pair of students engaged in constructing an appropriate synthetic pathway from initial reagents to the formation of final chemical product in a typical closed problem. Problems of this kind have been suggested to be simplistic as solutions can be reduced to routines or algorithms for which students can be trained to recall and utilize (Wood 2006). However, the choice of a closed problem for this study is deliberate in order to investigate the phenomenon of students' knowledge as multimodal, supported by an analytic focus on language in conjunction with action in forms of gestures and with the students' inscriptions. In this regard, the multimodal approach taken in this paper challenges the notion that students' science knowledge consists of propositions composed of well-defined concepts (Klein 2006) to reveal knowledge as an accomplishment of practical action (Garfinkel 1967) in the context of solving chemistry problems.

By looking at the types of semiotic resource employed for interaction and the functional role they play in students' problem-solving discourse, we aim to uncover and study the social creation and maintenance of scientific knowledge between students. The significance of such an approach is at least twofold: First, a multimodal approach can advance our knowledge about problem solving as more than consisting of cognitive strategies to encompass the use of meaning-making resources within the context and organization of participants' knowledge. It is vital that chemistry teachers recognize and value the constructive, persuasive, and reporting functions that language and other semiotic resources afford during scientific communication. In this way, teachers can examine and improve their own instructional practices on problem solving in order to model effective strategies for their own students. Second, a multimodal approach requires science educators to examine problem solving as a moment-by-moment unfolding event. This is important as close examination of students' engagement in problem solving allows the subtle nuances in speech and nonverbal behavior through which knowledge of science is represented, communicated, and developed to be studied. Hence, our understanding of the act of problem solving expands from knowing the cognitive strategies students employ to include how solutions to given problems are constructed, argued, and communicated through the dynamic interplay of speech, inscriptions, and gestures employed during the problem-solving process.

5.4 Methodology

Two female students, Sally and Heidi, volunteered for this study. They were first year Bachelor of Science (Education) undergraduates enrolled in a compulsory module on introductory organic chemistry. During the problem-solving session, the students were provided with an organic chemistry question (see below) printed on paper with blank spaces for their writings in addition to boxes of Molymod® models.

Using cyclohexene and bromine in carbon tetrachloride as starting materials, explain the synthesis of trans-1,2-dibromocyclohexane.

Problem solving can be defined as "figuring out what to do when one does not already know what to do" (Bowen and Bodner 1991, p. 143). While organic chemistry tutorial questions may look like mere exercises for chemists with wealth of chemical knowledge, the lack of familiarity with such problems for first year undergraduate chemistry students (Bodner and Domin 2000) makes this question about the synthesis of trans-1,2-dibromocyclohexane a challenging problem for them, not simply a recall exercise. The identities of the starting reagents were provided in the question so as to facilitate discussion about how the reagents may react. To solve the given organic chemistry problem, students needed to work out the solution in the following manner though not necessary in the linear order as presented in Fig. 5.1.

1. Draw the structures of cyclohexene and bromine.
2. Draw an arrow from double bond of cyclohexene to delta plus bromine.
3. Draw an arrow from the bond between the two bromine groups directed at the delta minus bromine.
4. Draw a bromonium intermediate with a positive charge.

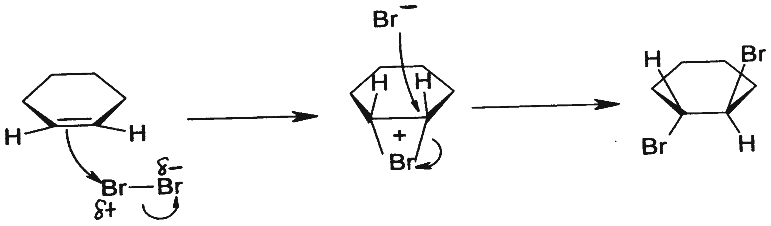


Fig. 5.1 Written solution to given interview question

5. Draw arrow to represent movement of bromide ion to either carbon involved in the bromonium intermediate.
6. Draw the configuration of the final product of trans-1,2-dibromocyclohexane.

The students were informed by the researchers that they could choose to answer the question in any form that they were comfortable with, even if that meant just talking about the question and not writing down anything on the given answer sheet. Students' engagements during the problem-solving session were video-recorded. Subsequently, the video recording was analyzed using Jordan and Henderson's (1995) interaction analysis approach where we ground our assertions in empirical evidence, building generalizations from records of naturally occurring activities and drawing upon our experience and expertise as chemists and chemical educators. The analysis begins with a description of the nature of the interactions obtained from repeated viewing of the two students solving the given organic chemistry problem. This description is followed by discussion focusing on how semiotic resources had been used by students to generate, organize, and communicate abstract scientific ideas during the problem-solving session. This is an iterative process where researchers would make assertions about the semiotic resources observed and the segment of video data was reviewed to check the degree to both researchers would agree to which assertion fits. When an assertion was agreed by all, more segments of video data were viewed in order to gather empirical evidence to support the claims. In cases where assertions were not agreed by all, assertions were reformulated and retested until a consensus that fitted the entire data was reached. To focus our attention on the repeated viewing of video data, we asked questions which were adapted from the work of Jordan and Henderson (1995) such as: What is the trajectory of the inscription/gesture/action? How did it get into and out of the scene? Who are the active agents employing the semiotic resource? How do they function in structuring interaction?

This resulted in labor-intensive work as close transcription of short strips of video recordings was created and individual lines of verbal transcripts were described with regard to duration, function of speech, action of participants, visual representation such as use of inscriptions or physical models, as well as the researchers' interpretations. The microanalysis of video segments, thus, afforded the means to describe dynamic activity involving the use of multiple meaning-making resources.

5.5 Findings

Sally and Heidi began by working out the structure of the final chemical compound and their process of problem solving revolved around the construction of isolated chemical structures. It is interesting to note that while their final written solution as shown in Fig. 5.2 seemed to indicate knowledge about the process of synthesis, their conversation revealed many areas of uncertainty.

5.5.1 *Final Chemical Structure*

Both students relied on gestures and speech to debate over which type of chemical structural representation to inscribe (Fig. 5.3). With her right-hand pointing finger raised, Sally produced an iconic gesture by tracing the outline of a six-membered carbon ring (Panel 1) as she offered verbal information about drawing a carbon structure (01).

Fig. 5.2 Final written solution of Sally and Heidi

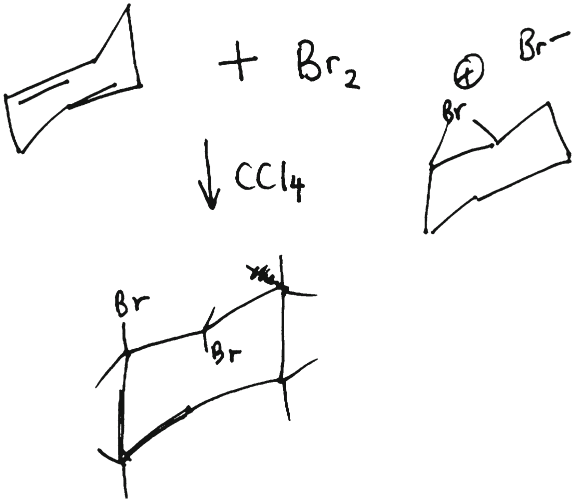


Fig. 5.3 Gesturing structures of final reagents

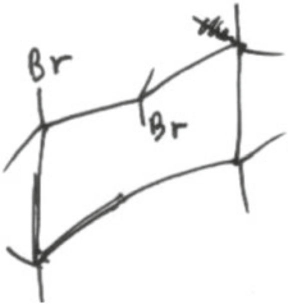


Fig. 5.4 Working out the spatial arrangement of substituent groups

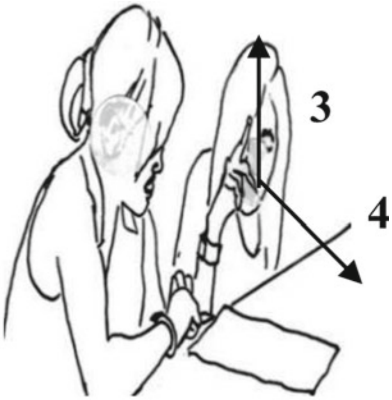
This gesture carried crucial information for Heidi who immediately offered an alternative structure by tracing in quick downward diagonal strokes on the table. While Heidi did not express verbally the chair conformer that she had in mind (02), her gestures illustrated clearly for Sally the chair conformer as an alternative to the cyclic skeletal representation. Although Sally expressed her uncertainty about Heidi's suggestion (03), she proceeded to draw the chair conformer of the final product (Fig. 5.3) which signaled the genesis of knowledge construction on paper.

Panel 1 Panel 2

01 Sally: Draw [carbon].
(*gestures in the direction of arrow, iconically sketching out a skeletal structure*)$_{\textit{Panel 1}}$
02 Heidi: [Draw that].
(*gestures in direction of arrows, iconically representing part of the chair structure*)$_{\textit{Panel 2}}$
03 Sally: Hmm, let's just try.
(*draws chair structure as shown below*)

After the inscription of carbon-hydrogen bonds in the chair conformer, Sally hesitated over the placement of the bromo groups and both students communicated with gestures again to determine the orientation of the two bromine substituent groups (Fig. 5.4). Heidi first asked Sally what "trans" might mean (04). Sally responded silently with a gesture where two pointing fingers were oriented perpendicularly to each other (Panel 3). Both bromo groups can be either in the equatorial positions or the axial positions in the chair conformation of the final trans compound. However, Sally's gesture seemed to indicate an orientation where the substituent groups are 90° away from each other. Her gestures were followed up subsequently with a tentative verbal request for Heidi's affirmation (06). While Sally positioned her pen over the chair conformation of the final structure, Heidi reasoned verbally that if one bromo group was drawn pointing upward, the other should be pointing downward (07). Observing the directions of her pointing figures (Panel 4), the angle between the instance of pointing upward and downward embodied Heidi's conception of the manner in which bromine groups are attached to the cyclic ring. This gesture was similar to Sally's except that the angle between the upward and downward pointing finger was greater. This information was repeated as Heidi this time flipped her right hand in an up-down manner (Panel 5) to demonstrate that her verbal utterance of "opposite side" (08) entailed a direct up-down orientation as materially carried in her gesture. Sally took up Heidi's suggestion and drew the bromo groups in the axial positions (Fig. 5.4).

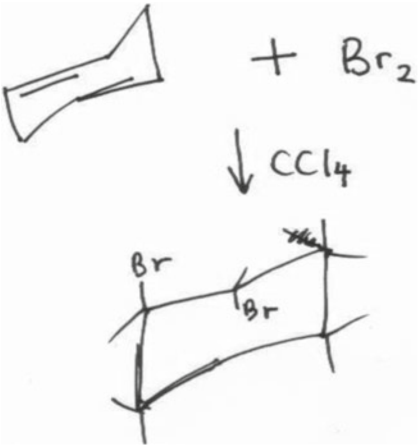
Panel 3

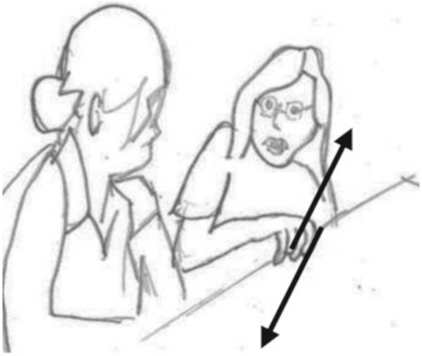


Panel 4

04 Heidi: Trans 1 2 dibromo, trans is?
05 Sally: […]
(*gestures up and down in opposite direction indicated by arrow1 and 2*)$_{\text{Panel 3}}$
06 Sally: Should be. Is that right?
07 Heidi: Trans [should be one up and down].
(*gestures in the direction of arrow 3 and arrow 4*)$_{\text{Panel 4}}$
08 Heidi: Trans. They are in [opposite side]$_{\text{Panel 5}}$. If you put one up the other will be down.

Fig. 5.5 Gesturing to determine structure of initial reactant





Panel 5

(*right hand raised, flipping upward and downward in quick succession*)$_{Panel\ 5}$
(*Sally draws position of two bromine groups as shown below*)

5.5.2 Initial Chemical Structures

After the final chemical product was inscribed, Sally began another phase of problem solving as she prepared to construct the initial reagents. First, she signaled her thoughts about the location of a double bond in the reactant by tracing two parallel lines along the inscribed final compound (Panel 6). Verbally, Sally also informed Heidi that they had to place a double bond at the location where she had previously gestured over (09) and proceeded to draw a cyclohexene at the upper section of the page (Fig. 5.5). Sally subsequently completed the equation with further inscriptions of the chemical formula of Br_2, CCl_4, and the reaction arrow pointing downward to the product.

Panel 6

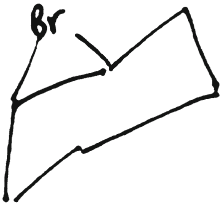
09 Sally: Ok, so we have to put a [double bond here].
(*gestures in direction of arrows twice as shown above over the structure of final product*)
10 Sally: And [reaction with bromine].
(*draws starting compound and writes* Br_2 *and arrow pointing downward with* CCl_4 *inscribed on right side of arrow*)

5.5.3 Intermediate Structure

The pair of students next engaged in drawing "something else" (11). Heidi began by first suggesting to Sally that their written solution required another chemical structure (11). With her fingers held in an inverted cup shape directed at the answer sheet (Panel 7), the metaphoric gesture encapsulated the hazy notion of the intermediate in which speech was equally vague with an ambiguous reference of "something else." Sally interjected to offer new information that the intermediate had a "wing" (12) in rapid speech and repeatedly traced a triangular outline on paper (Panel 8).

After each student had contributed her own ideas about the intermediate, Heidi signaled her readiness to construct the chemical structure on paper by suggesting "let's try" verbally (13). Voicing her thoughts (14), Sally simultaneously outlined the three-membered ring with a clenched fist over the inscription of the starting chemical reagent before drawing the intermediate structure in Fig. 5.6.

Fig. 5.6 Verbal-gestural exchange leading to inscription of intermediate



Panel 7 Panel 8

11 Heidi: I think we need to draw something else right?
(*cupped left hand directed downward at table*)$_{Panel\ 7}$
12 Sally: Something that has a wing…
(*traces shape of triangle with finger*)
13 Heidi: Let's try.
14 Sally: I remember there is a [three member ring].
(*traces shape of triangle with clenched fist over previously drawn starting reagent*) $_{Panel\ 8}$
15 Heidi: I think that's right. Correct, correct.
(*Sally proceeds to draw the bromonium ion intermediate*)

Evaluating the completed structure of the intermediate, Heidi suggested, through an interrogative request, a positively charged bromonium intermediate (16). Heidi's evaluation of the incomplete intermediate chemical structure led Sally to draw a positive charge and a bromide anion in the diagram (Fig. 5.7). Through inscriptional means, Sally acknowledged the information provided by Heidi and at the same time contributed her share of knowledge with an inscription of the bromide ion.

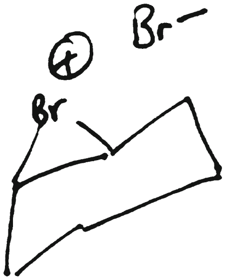


Fig. 5.7 Inscription of intermediate of reaction

16 Heidi: Br, is it positive?
17 Sally: Let's try.
(*adds in positive sign for carbocation and draws a bromide ion*)
18 Sally: Something like that.

5.6 Discussion

Analysis of this single case study leads to two points of discussion. First, we claim that this chemistry problem-solving event involving the two students serves as an exemplar to highlight problem solving as a practical activity of human interaction which goes beyond the confines of cognitive processes to encompass a strategic use of meaning-making resources to construct knowledge as well as report the knowledge to others and persuade others of their validity. By providing detailed description about the events leading to the final solution and the specific ways in which they were constructed through speech, visual inscriptions, and gestures, we show how students collaborate using a myriad of meaning-making resources to construct a reasonable solution. While a conceptual base of content knowledge (Krange and Ludvigsen 2008), mathematical knowledge (Chandrasegaran et al. 2009), and procedural knowledge is necessary for problem solving, it does not preclude the use of meaning-making resources for building new knowledge contingent upon previously constructed knowledge along the pathway of problem solving as exemplified in this case study. Second, we provide a method for investigating problem solving from a multimodal perspective that goes beyond the typical focus on cognitive processes of students during problem solving. Through interaction analysis, which provides a fine comb to untangle the intricacies of student interactions as a multimodal event, data can be examined repeatedly by focusing on the ways students interact and the role of meaning-making resources in the accomplishment of the activity.

In this case example, the students were uncertain of the process of addition reaction mechanism. First, they focused upon the final product and worked backward to derive the structure of the starting compound which indicated their lack of knowledge about how to solve the problem beginning from the starting reagents. Second, in the inscription of the final product, students were unaware of the placement of the two bromine groups in the equatorial position to prevent 1,3-diaxial interactions. Third, the students' focus on the inscription of the intermediate to mediate between the starting and final chemical structures can be understood as filling in a gap in order to fulfill the requirements of the given problem. The lack of inscriptions of arrows symbolizing the movement of electrons as well as the absence of verbal or gestural reference to electron movement indicate that the students may not be aware of the electron movements in the addition reaction process.

Despite their lack of understanding of the addition reaction mechanism, they were able to collaboratively generate a final solution on paper. In fact, the coordination of semiotic resources was critical in enabling both students to solve the given problem. First, gestures enabled students to agree upon an outline for the structure of the final product, 1,2-dibromocyclohexane (01–03). Next, transformation of gestural information occurred as the chair conformer of the final trans product was revealed through visual inscription on paper (04–08). This inscription provided the platform for Sally to gesture over it the location of the double bond of the starting chemical compound, cyclohexene (09). Subsequently, the gestural information was marked down on paper through Sally's drawing of cyclohexene (09–10).

Students had also relied upon gestures to communicate their ideas about the intermediary product formed during the reaction, the bromonium ion intermediate (11–14). Relying on speech alone, we might be left wondering what the students were talking about as it was mostly restricted to verbal request for inscriptions or to seek affirmation of drawings or verbal expressions that need to be understood in relation to what had been gestured or drawn on paper. Observing the iconic gestures Sally produced with her finger over the starting compound in a triangular manner coupled with our knowledge of organic chemistry, we may interpret her gestures in this instance to embody the bromonium ion intermediate where the bromine is attached to two carbon atoms through partial bonds. This contrasted with Heidi's metaphoric gesture where she appeared to be holding down an object in her hand. Thus, the students' gestures embodied the intermediate they had in mind (11–14) while visual inscription was used as a means to concretize the structural information of the intermediate expressed through speech and gestures. Hence, based on the gestures produced, Heidi was able to verbally assure Sally that they were on the right track resulting in Sally inscribing the intermediate (15) which followed closely her gestures of the triangular "wing" structure in Fig. 5.6. In summary, the information as revealed through the three semiotic resources indicated that the students' knowledge about the addition reaction was only sufficient to solve the given problem superficially and that they lacked an in-depth understanding of the reaction mechanism.

The implication of this case study is at least twofold. First, it is necessary to raise awareness of multimodality of concepts among teachers and students. Focusing on nonverbal aspects of communication in addition to written and spoken words to construct, persuade, and report may provide teachers with new resources that will enhance their teaching. For example, our findings highlight students' use of gestures for the representation of chemical structures. Therefore, teachers can also use gestures in additional to speech and writings during instructional discourse as a means for helping students visualize chemical structures as part of the scientific modeling process.

Second, assessment practices need to include at least both visual and verbal modes of representation for students. For instance, if the assessment intent is to elicit students' understanding of reaction mechanisms, undergraduate chemistry assessments need to include a variety of activities such as oral examinations and performance tasks in which students can use inscriptions, gestures, or even modeling software in addition to speech to explain chemical phenomenon. In this way, students are provided with more opportunities to present their knowledge using a variety of modes. Reliance on written examinations confines students to the use of only writings and inscriptions. However, by providing students more opportunities to "talk chemistry," teachers can pay attention to their students' gestures and verbiage in addition to writings to assess scientific ideas of the students.

In the same vein, students may be able to better articulate their conceptions and understandings when a multitude of resources such as gestures in addition to speech and writings are made available. Especially when we are interested to develop students' problem-solving skills to rise above the realm of rote algorithmic manipulations into the realm of creative problem solving (Wood 2006), we need to provide opportunities for students to employ some of these nonverbal resources when they are communicating with teachers and peers. Our collection of empirical evidence positions the gestures of Sally and Heidi explicated in previous section as not just random acts of hand-waving. Their gestures embodied their thoughts which led to the accomplishment of their task. This also lends further support to the argument that gestures are meaning-making resources which students can rely upon to construct and communicate scientific concepts (Goldin-Meadow and Wagner 2005; Pozzer-Ardenghi and Roth 2007).

5.7 Conclusion

In summary, through a close examination of how two students engage in solving organic chemistry problems, the cognitive focus on students' learning (Johnstone 2000; Johnstone and Kellett 1980) is broaden to include a multimodal view of problem solving. This perspective positions students' engagement with scientific tasks as an accomplishment through coordination of semiotic resources where students are engaged in the process of using and the reshaping of resources (Kress et al. 2001). This has potential to unveil what students have in mind, which also in turn shapes their subsequent responses. While many teachers emphasize the reporting function of print and visual representations, it is important that teachers also recognize these semiotic resources as cognitive tools to construct and convey scientific ideas.

Therefore, students need to be given opportunities to use multiple representations central to the practices of scientific communication as a way to support, develop, and showcase their understanding of scientific phenomena. This suggestion is congruent with calls for the development of representational skills as part of the chemistry curriculum and the use of these skills to better understand and assess the chemistry knowledge of our students (Kozma et al. 2000).

References

Airey, J., & Linder, C. (2009). A disciplinary discourse perspective on university science learning: Achieving fluency in a critical constellation of modes. *Journal of Research in Science Teaching, 46*(1), 27–49.

Anderson, T. L., & Bodner, G. M. (2008). What can we do about 'Parker'? A case study of a good student who didn't 'get' organic chemistry. *Chemistry Education Research and Practice, 9*(2), 93–101.

Bennett, S. W. (2008). Problem solving: Can anyone do it? *Chemistry Education Research and Practice, 9*(1), 60–64.

Bezemer, J., & Kress, G. (2008). Writing in multimodal texts: A social semiotic account of designs for learning. *Written Communication, 25*(20), 166–195.

Bhattacharyya, G. (2004). *A recovering organic chemist's attempts at self-realization: How students learn to solve organic synthesis problems*. Unpublished Doctoral Dissertation, Purdue University, West Lafayette, IN.

Bhattacharyya, G., & Bodner, G. M. (2005). "It gets me to the product": How students propose organic mechanisms. *Journal of Chemical Education, 82*(9), 1402–1407.

Bodner, G. M., & Domin, D. S. (2000). Mental models: The role of representations in problem solving in chemistry. *University Chemistry Education, 4*(1), 24–30.

Bodner, G. M., & Herron, J. D. (2002). Problem solving in chemistry. In J. K. Gilbert, O. D. Jong, R. Justi, D. F. Treagust, & J. H. Van Driel (Eds.), *Chemistry education: Towards research based practice* (pp. 235–266). Dordrecht: Kluwer Academic Publishers.

Bodner, G. M., & Pardue, H. L. (1995). *Chemistry: An experimental science* (2nd ed.). New York: Wiley.

Bodner, G. M., & Weaver, G. (2008). Research and practice in chemical education in advanced courses. *Chemistry Education and Research Practice, 9*(4), 81–83.

Bowen, C. W. (1990). Representational systems used by graduate students while problem solving in organic synthesis. *Journal of Research in Science Teaching, 27*(4), 351–370.

Bowen, C. W., & Bodner, G. M. (1991). Problem-solving processes used by students in organic synthesis. *International Journal of Science Education, 13*(2), 143–158.

Chandrasegaran, A. L., Treagust, D., Waldrip, B. G., & Chandrasegaran, A. (2009). Students' dilemmas in reaction stoichiometry problem solving: Deducing the limiting reagent in chemical reactions. *Chemistry Education Research and Practices, 10*(1), 14–23.

Dori, Y. J., & Barak, M. (2001). Virtual and physical molecular modeling: Fostering model perception and spatial understanding. *Educational Technology & Society, 4*(1), 61–74.

Florence, M. K., & Yore, L. D. (2004). Learning to write like a scientist: Coauthoring as an enculturation task. *Journal of Research in Science Teaching, 41*(6), 637–668.

Gabel, D. L., & Bunce, D. M. (1994). Research in problem solving: Chemistry. In D. L. Gabel (Ed.), *Handbook of research in science teaching and learning* (pp. 301–326). New York: Macmillan.

Gabel, D. L., Sherwood, R. D., & Enochs, L. (2006). Problem solving skills of high school chemistry students. *Journal of Research in Science Teaching, 21*(2), 221–233.

Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs: Prentice Hall.

Goldin-Meadow, S., & Wagner, S. M. (2005). How our hands help us learn. *Trends in Cognitive Science, 9*(5), 234–241.

Hand, B., & Choi, A. (2010). Examining the impact of student use of multiple modal representations in constructing arguments in organic chemistry laboratory classes. *Research in Science Education, 40*(1), 29–44.

Johnstone, A. H. (2000). Teaching of chemistry: Logical or psychological. *Chemistry Education: Research and Practice in Europe, 1*(1), 9–15.

Johnstone, A. H., & Kellett, N. C. (1980). Learning difficulties in school science-towards a working hypothesis. *International Journal of Science Education, 2*(2), 175–181.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences, 4*(1), 39–103.

Klein, P. D. (2006). The challenges of scientific literacy: From the view-point of second generation cognitive science. *International Journal of Science Education, 2*(2/3), 143–178.

Knain, E. (2006). Achieving science literacy through transformation of multimodal textual resources. *Science Education, 90*(4), 656–659.

Kozma, R. (2003). Material and social affordances of multiple representations for science understanding. *Learning and Instruction, 13*(2), 205–226.

Kozma, R., Chin, E., Russell, J., & Marx, N. (2000). The role of representations and tools in the chemistry laboratory and their implications for chemistry learning. *Journal of the Learning Science, 9*(3), 105–144.

Krajcik, J. S. (1991). Developing students' understanding of chemical concepts. In S. M. Glynn, R. H. Yeany, & B. K. Britton (Eds.), *The psychology of learning science* (pp. 117–147). Hillsdale: Lawrence Erlbaum.

Krange, I., & Ludvigsen, S. (2008). What does it mean? Students' procedural and conceptual problem solving in a CSCL environment designed within the field of science education. *International Journal of Computer-Supported Collaborative Learning, 3*(1), 1556–1607.

Kress, G. (2003). *Literacy in the new media age*. London: Routledge.

Kress, G., Jewitt, C., & Tsatsarelis, C. (2000). Knowledge, identify, pedagogy: Pedagogic discourse and the representational environments of education in late modernity. *Language and Education, 11*(1), 7–30.

Kress, G., Jewitt, C., Ogborn, J., & Tsatsarelis, C. (2001). *Multimodal teaching and learning: Rhetorics of the science classroom*. London: Continuum.

Lee, K. L., & Fensham, P. (1996). General strategy for solving high school electrochemistry problems. *International Journal of Science Education, 18*(5), 543–555.

Lemke, J. L. (1998). Multiplying meaning: Visual and verbal semiotics in scientific text. In J. Martin & R. Veel (Eds.), *Reading science: Critical and functional perspectives on discourses of science* (pp. 87–113). London: Routledge.

Lemke, J. L. (2001). Articulating communities: Sociocultural perspectives on science education. *Journal of Research in Science Teaching, 38*(3), 296–316.

McLoughlin, C., & Taji, C. (2005). *Teaching in the sciences: Learner centered approaches*. Binghamton: The Haworth Press.

Nakhleh, M. B., & Postek, B. (2008). Learning chemistry using multiple external representations. In J. K. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 209–231). Dordrecht: Springer.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2), 224–240.

Pozzer-Ardenghi, L., & Roth, W.-M. (2007). On performing concepts during science lectures. *Science Education, 91*(1), 96–114.

Schank, P., & Kozma, R. (2002). Learning chemistry through the use of a representation-based knowledge building environment. *Journal of Computers in Mathematics and Science Teaching, 21*(3), 253–279.

Stieff, M. (2007). Mental rotation and diagrammatic reasoning in science. *Learning and Instruction, 17*(2), 219–234.

Tsaparlis, G., & Angelopoulos, V. (2000). A model of problem solving: Its operation, validity and usefulness in the case of organic synthesis problems. *Science Education, 84*(2), 131–153.

Wood, C. (2006). The development of creative problem solving in chemistry. *Chemistry Education and Research Practice, 7*(2), 96–113.

Yore, L. D., & Treagust, D. F. (2006). Current realities and future possibilities: Language and science literacy – Empowering research and informing instruction. *International Journal of Science Education, 28*(2/3), 291–314.

Zoller, U., & Pushkin, D. (2007). Matching higher-order cognitive skills (HOCS) promotion goals with problem-based laboratory practice in a freshman organic chemistry course. *Chemistry Research Education and Practice, 8*(2), 153–171.

Chapter 6

Understanding Photosynthesis and Respiration: Is It a Problem? Eighth Graders' Written and Oral Reasoning About Photosynthesis and Respiration

Helena Näs

6.1 Introduction

At the senior level of the 9-year compulsory schooling in Sweden, photosynthesis and respiration play an important part in biology curricula. One important objective is that the student, at the end of year 9, should 'have an insight into photosynthesis and combustion, as well as the importance of water for life on earth' (The Swedish National Agency for Education 2009). Other objectives are to develop knowledge about organisms and their interplay with the environment and to understand cell and life processes, so knowledge about photosynthesis and respiration is essential (ibid).

Students at almost all school levels, from 9 to 19 years of age, show difficulties in understanding photosynthesis and respiration, and there also seems to be a fundamental lack of understanding of basic ecological concepts, for example, energy flow in ecosystems, including the role of photosynthesis and respiration for life on earth (Canal 1999; Marmaroti and Galanopoulou 2006; Wood-Robinson 1991). Research reports from three different decades show the persistence of the intuitive explanation that plants get their food from their environment, specifically, from the soil, where the roots are the organs of feeding (Andersson 2008; Driver et al. 1994; Smith and Anderson 1984). Understanding of photosynthesis depends on understanding particle theory, changes of phase and transformation, concepts that students have difficulty grasping (Carlsson 1999). According to Barak (1999), teaching focuses mainly on learning words at the expense of the understanding of concepts and the life processes. When photosynthesis is not truly understood, the students tend to

---

H. Näs (✉)
Department of Science and Mathematics Education, Faculty of Science and Technology,
University of Umeå, Umeå, Sweden
e-mail: Helena.nas@matnv.umu.se

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_6,

use rote memorization as a strategy, and their knowledge is not meaningful (Canal 1999). Understanding complex topics in ecosystems requires deep understanding of concepts like photosynthesis and respiration and how to relate them to the whole system (Helldén 2005; Hogan and Fisherkeller 1996; Magntorn 2007). Thus, learning about ecology provides an opportunity for students to relate photosynthesis and respiration to the whole system. Even so, results from Özay and Öztas (2003) show that students aged 15 did not understand photosynthesis after learning about ecology.

Many of the above-mentioned difficulties are demonstrated in results from high stakes testing. Written tests are a common way to evaluate students' knowledge both in school, National Evaluations (NE) (NE 1992, 2003), and international surveys (TIMSS and PISA). However, one question is whether these surveys accurately reflect the knowledge of the students. Schoultz et al. (2001) showed how students' difficulties in answering two items from a TIMSS' test were easily addressed in an interactive setting where the students discussed and answered the TIMSS' items together with the researcher, and they expressed doubts if these items actually tested conceptual knowledge.

According to Andersson (2008), both everyday language/thinking and scientific language/thinking play a crucial role in understanding science. It is important for students to learn how to move between everyday and scientific thinking. Andersson's assertion is based on empirical data and Piaget's and Vygotskij's theoretical descriptions about everyday and scientific knowledge. Using living plant material as artefacts in teaching is a way to attain an ecological interest and understanding and provides good learning opportunities about photosynthesis in early grades (Helldén 1992; Näs and Ottander 2008; Vikström 2005). Vikström used the life cycles of plants, seeds and angiosperms to demonstrate how 7- to 12-year-old students developed complex understanding of photosynthesis when their teachers used language that included metaphors and when they pointed out critical aspects, like how the sugar is needed and used in the plant. Magntorn and Helldén (2007) described a 'bottom-up' perspective in teaching primary students about ecosystems, which took, as a starting point, the freshwater shrimp, an organism in a river ecosystem near the children's school. By connecting the environment and other organisms' dependence on the freshwater shrimp, the students gained an interest in and acquired a better understanding of many ecological concepts and processes.

Teenagers' lack of interest in describing and understanding ecological concepts like food webs, recycling and energy transformations tells us that new ways of teaching ecology are needed (Barker and Slingsby 1998; Delpech 2002; Driver et al. 1994; Feinsinger et al. 1997). Delpech pointed out that it is important for the teacher to give students opportunities to express their knowledge in ways beyond memorised facts. According to Slingsby and Barker (2003) biology teachers need to include ethical and emotional aspects in their practice to enhance new factual knowledge. They also suggested that 'once the students have been taught the science they need to be put in the place of someone who has just discovered they have cancer or they need to consider how climate change could effect them' (p. 5).

Enquiry-based teaching, group work, outdoor education and ethical and emotional discussions need supportive and experienced teachers if the students are to learn and understand difficult science concepts (Delpech 2002; Näs and Ottander 2009; Vikström 2008).

Probing students' reasoning gives a teacher interesting insights into their understanding and thoughts (Driver et al. 1996; Mortimer and Scott 2003; Schoultz et al. 2001). Driver et al. listened to students' reasoning during work with different scientific problems outside the classroom. In their analyses, they tried to describe the learning process of the students. Schoultz and colleagues used items from TIMSS and could therefore compare the understanding the students showed in a communicative format to the understanding measured in TIMSS' assessment.

This chapter focuses on students' written and oral knowledge and reasoning about photosynthesis and respiration before and after ecology instruction. The following questions are addressed:

What knowledge about photosynthesis and respiration do the students demonstrate in written tests and in a guided interview?

How does the reasoning of students differ in a written test and in a guided interview?

6.2 Method

6.2.1 The Ecology Unit

The ecology unit ran for 10 weeks with each class having 33 h of lessons. Table 6.1 presents the activities during the ecology unit, and results from the parts in bold are presented in this chapter.

6.2.2 Students and Teachers Involved

Three eighth grade classes and their two teachers participated in the study. The teachers managed all lesson plans and the teaching. The teachers described the classes as two normal classes and one problematic one. One teacher taught the problematic class (18 students) where most of the students were disruptive and not focused on the school work, while the other teacher taught the other two classes (24 and 27 students, respectively) where most of the students were interested in their school work. The students had been taught photosynthesis and respiration in sixth and seventh grades, but the teachers wanted to reinforce the content in the ecology unit. In line with Swedish ethical requirements (The Swedish Research Council 2002), all students and their parents were asked for permission to allow me to observe the lessons and for the follow-up interviews.

Table 6.1 Time used at each part, teachers' lesson plans and the researcher's data acquisition

Week and time used	Activities carried out in each of the three classes	Data acquisition
1–2, 6 h	Introduction to ecology with cultivation and group work about leaving earth and the survival on a space shuttle	Observation notes in all the three classes
3, 3 h	Theory lessons in ecology and group work as a preparation for the excursion to the forest biotope. **Pre-test questionnaire** (Andersson et al. 2009). $n = 59$	Observation notes and 59 collected questionnaires
4, 6 h	The excursion and supplementary group work	Observation notes
5, 3 h	Supplementary work with excursion material and theory lessons	None
6–8, 9 h	Theory lessons with ecology, photosynthesis and respiration content carried out in lectures, group work and individual work with questions from the textbook interspersed with demonstrations and laboratory work	Observation notes and audiotaped discussions partly transcribed
9	Autumn holiday	None
10, 3 h	Review of the ecology content	Observation notes
11, 3 h	Repetition lessons before test and one lesson's **written test (post-test, mostly teacher constructed, Appendix) as an examination of the whole ecology unit**	Observation notes, 66 collected and copied tests
14–16, 12 h	**Interviews with 23 students**	Audiotaped interviews fully transcribed

6.2.3 *The Pre- and Post-test and Analysing Strategies*

This chapter reports the results of responses to three essay questions (questions 9, 17 and 20, Appendix) which were included in both pre- and post-tests. These questions are part of a workshop used in Swedish in-service training courses on the Internet, NORDLAB-SE (Andersson et al. 2009). The pre-test was given to 59 students in the third week just before the ecology and photosynthesis/respiration lessons started (Table 6.1). There were altogether 69 students, but non-attendance and illness were the reasons that 59 students did the pre-test and 66 did the post-test. The written answers were analysed and categorised with three aims:

- To examine the written reasoning of the students
- To compare the written answers with the results of two National Evaluations[1] (NE)
- To compare the written reasoning of 23 interviewed students with their oral reasoning

---

[1] Three thousand one hundred Swedish students in 1992 and 620 students in 2003. http://www.skolverket.se/

Table 6.2 The interview guide

Question	My aim
Tell me something about yourself!	To get to know and make them relax
Tell me something about the unit you just have finished. Do you remember anything in particular?	To talk about the ecology unit by letting the students mention the science words, processes or concepts
Do you remember the space shuttle? If you were told to do it now, would you change your equipment and plans?	To mention an actual part of the teaching like the space shuttle and to investigate their knowledge about that part
What do you think about photosynthesis? Is it important? Where is oxygen used? What is respiration?	To make them start reasoning about photosynthesis and respiration
Branches of pine and spruce, a potato, a carrot and an apple were used. How does this become a pine, potato, etc.? What is it made up of?	To see if they could use their knowledge about photosynthesis and respiration with a plant or a fruit in their hands

Three answer categories were constructed: (1) correct, (2) not comprehensive and (3) no or irrelevant answer (cf. Tables 6.3 and 6.4). These three categories were an amalgamation of the National Evaluation's (1992, 2003) nine categories used on the essay question 'the growing tree' (question 9, Appendix). This study's 'correct' category correspond to the two first categories of NE, where the passing grade required carbon dioxide in the answer, perhaps in any combination with nutrition, water and sun energy, and the pass with distinction grade required a more scientific explanation. The NE used five categories to differentiate answers where the students tried to explain but used the science words and concepts both incorrectly and incompletely or fragmentarily in diverse combinations. In this study, these five categories were united into one 'not comprehensive' category since these answers corresponded to attempts to give a correct answer. The third category used in this study was a 'no answer' or 'other' category, so the incorrect answers in this study are described by the 'not comprehensive' and 'no answer' or 'other' categories. All answers to the three essay questions (the growing tree, the polar bear and the terrarium) are categorised and analysed in the same way.

6.2.4 The Interviews

Twenty-three students were interviewed on their understanding of photosynthesis and respiration and how the ecology unit was taught, on a voluntary basis. The composition of the interviewed group corresponded to the three classes' diversity and composition of strong and weak students. The specific subject content was introduced by means of questions and material (branches of trees, potato, apple and carrot). The interview guide is shown in Table 6.2. During the semi-structured interviews, the students were encouraged to explain their reasoning and deviation from the guide occurred when unexpected threads were pursued.

6.2.4.1 Analysis of the Interviews

During the interviews, the students were encouraged to elaborate on their explanations, applications and guesses about plant life and other organisms' dependence on plant life to gain insights into the students' thoughts and knowledge. The reasoning capacity of the students was continuously interpreted (Bogdan and Biklen 2003; Erickson 1986). Kvale's (1996) first three steps in the analysis of qualitative interviews (pp. 189–190) were used: (1) the interviewee's short description of herself, (2) the interviewee finds out new ways of thinking or understanding connections and (3) the interviewer tries to help the interviewee to focus and elaborate on what they said during the interview (Table 6.2). The interpretation of the reasoning of the interviewee started with the transcription of the audiotaped interviews and then continued with its categorisation (i.e. Kvale's fourth step). The transcripts were read many times with an aim to understand each student's reasoning. Some of the interviews were also read and interpreted by another researcher to ensure similar interpretations. In the beginning, the interviews of the boys and girls were analysed separately. As more gender similarities than differences were noted, the interviews of the boys and girls were analysed together. The reasoning categories used in the analyses are:

1. The 'linking-together' reasoning: The students mainly linked scientific concepts and words to form a whole description by using more everyday language rather than scientific language.
2. The 'memory' reasoning: The students mainly presented their knowledge by using memorised formulations and correctly articulated scientific concepts.
3. The 'school-weary' reasoning: The students mainly maintained that they did not know anything and that the science content and lessons were boring.

6.3 Results

6.3.1 Written Knowledge

Table 6.3 displays how the students answered the essay questions in the pre- and post-tests. The questions dealt with photosynthesis (the growing tree) and carbon recycling (the polar bear and the terrarium). Overall, the written responses to the growing tree and the terrarium questions were better formulated than the polar bear question (cf. 6.3.1.1). More than three times as many students did not give an answer or gave an irrelevant answer in the polar bear question compared to the other two questions.

In the growing tree question, the students showed a prominent improvement after teaching with an increase from 22% to 59% in the 'correct' category. The polar bear and the terrarium question did not produce the same steep increase, but the increases, 18% and 15%, respectively, were evident. The figures indicate that students enhanced

Table 6.3 The students' pre- and post-test answers in the questions 9, 17 and 20 (Appendix)

Category	Growing tree		Polar bear		Terrarium	
Pre and post	Pre	Post	Pre	Post	Pre	Post
Correct	22%	59%	16%	34%	37%	52%
Not comprehensive	56%	29%	25%	24%	33%	33%
No or irrelevant answer	22%	12%	59%	42%	30%	15%

Table 6.4 The results from the question about the growing tree in the NE (1992) and (2003)

Category	1992 ($n=3{,}103$)	2003 ($n=620$)
Correct	5%	8%
Not comprehensive	73%	47%
No or irrelevant answer	23%	45%

their knowledge of both photosynthesis and respiration, but respiration was more difficult to explain or understand. In the 'not comprehensive' category, there was a sharp decrease in the growing tree question, whereas the polar bear and the terrarium question did not alter. There were more than three times as many students that gave no or an irrelevant answer in the polar bear question (42%) in the post-test compared to the growing tree (12%) and the terrarium questions (15%).

The students' answers to the growing tree question (in both pre- and post-test) differed substantially from the results of the National Evaluation (NE). The correct answer category was three to four times higher in the pre-test and seven to ten times higher in the post-test (Table 6.3) compared to the results of the same question on the NE (Table 6.4). The high percentage in the no or irrelevant category in the NE of 2003 is also worth noting. The NE are distributed to the schools any time during the year, and the students are in the same age as the students in this study, but the topics (e.g. photosynthesis and respiration) have not necessarily been taught immediately before the NE so the results from the NE and this study may not be a fully fair comparison.

6.3.1.1 Written Answers to the Three Essay Questions

Five students' written answers in the post-test are shown below. In Sects. 6.3.2.1, 6.3.2.2, 6.3.2.3 and 6.3.2.4, these students' oral reasoning is reported.

The growing tree: 'Where does the biomass come from?' (question 9, Appendix)

To the growing tree question, all answers except Evelina's was categorised as 'correct'. Her answer was categorised as 'not comprehensive'. The 'not comprehensive' answers could be given points by the teacher but never up to a passing level.

Jonas: Carbon by means of taking in carbon dioxide and using the carbon to build up itself and then it gets nutrients from the soil that it also uses to build up itself.

Sara: It comes from the air. The tree needs carbon dioxide to grow and the bigger it gets it will need more carbon dioxide … so the air and the sun's energy is the tree's 'food'.

Sune: The 250 k come from the plant's photosynthesis. The glucose that is caught is partly used by the plant to build itself up.

Evelina: Energy from the sun.

Timon: The tree has picked up energy and carbon dioxide and formed it into glucose and oxygen. The plant eats off the glucose and transforms it into building blocks so the tree can grow.

The polar bear: 'Describe the journey of carbon atoms' (question 17, Appendix)

Timon did not answer the polar bear question, but the other students tried to give a scientific explanation. Sune was the only one who combined photosynthesis and respiration and gave a correct explanation. Jonas gave a long answer categorised as 'not comprehensive'. His answer described population ecology theories but not carbon recycling. It is possible that he did not understand the question, but he tried (like in the growing tree) to put the carbon atom in a meaningful context. Student responses that indicated some knowledge of molecules and the transformation from one form to another, but did not correspond to a full explanation, were categorised as 'not comprehensive'.

Jonas: A polar bear swam to Norway and a wolverine there bit it in the leg. This passed the carbon atom to the wolverine and he started to migrate to Sweden where he found a female that he mated with and then it has been passed on through generations.

Sune: The carbon atoms are spread in the wind and come to a flower in the Swedish mountains. Then a field mouse eats the plant and gets the carbon atom. The wolverine then eats the mouse and gets the atom.

The terrarium: 'What will happen in the jar if you do not open the lid?' (question 20, Appendix)

The students' answers in the terrarium question were difficult to categorise since the formulation 'What will happen' did not depend upon any scientific explanation. Evelina's answer 'There will still be plants in it after five years' therefore was deemed as a correct answer although that answer did not describe any understanding of carbon recycling. Sara's answer was categorised as 'not comprehensive' though she tried to explain with the use of carbon dioxide. Sune's response was again categorised as correct.

Sara: The plants die as they need carbon dioxide to live, and when you put a lid on, there will be no carbon dioxide. That is why the plants die because they need carbon dioxide to make glucose and without carbon dioxide everything stops.

Sune: The plants grow slowly but surely since the oxygen and carbohydrates, made in the photosynthesis, are used in the respiration and there it'll form carbon dioxide, water and energy that are used in the next photosynthesis and like that it goes on. Photosynthesis = carbon dioxide + water + energy = oxygen + glucose.

6.3.2 *Reasoning During the Interviews*

One third of the students taking the ecology unit were interviewed. At the start, some of the students did not want to say anything, and they needed encouragement to do so. However, when they realised that they were allowed to use everyday knowledge in their reasoning and explanations, using a mix of school science and everyday experiences, they started to show that they had an understanding of the concepts. Branches of pine and potatoes helped the weaker students to construct explanations, and the more competent students had 'aha' moments when they realised that photosynthesis and respiration were something more than just formulas. During the interview, the experience of the researcher helped the students to broaden and deepen their understanding (cf. Schoultz et al. 2001). Parts of the interviews below show how each student often used two types of reasoning (cf. Fig. 6.1) in their explanations.

6.3.2.1 Linking-Together Reasoning

The interview with Jonas was easy to conduct since he was confident, easy to talk to, thoughtful and reflective in his reasoning. He said that the ecology unit had been interesting and he highly commended the practical parts such as the ecology excursion in the woods and the experiments with plants. When he held a potato in his hand, he directly connected the photosynthesis of the potato plant with the production of potatoes beneath the soil. Jonas used both scientific and everyday language in his explanation.

In the excerpts, the interviewer (=I) and the student's first letter, for example, Jonas (=J)

J: *It gets like a photosynthesis…*
I: Yes what is that?
J: *It's like… when the plant mixes sunlight, water and air into energy… or not air, carbon dioxide and then transforms these into air and energy… I mean glucose.*
I: Exactly, if you say that you have carbon dioxide in the mixture from start… what do you get afterwards?
J: *Then it will only be oxygen. Because it makes use of the carbon dioxide, there, together with the energy…*
I: Yes, what happens to the carbon dioxide?
J: *I don't know… it stores it?*

His explanation below of how dextrose[2] pastilles were produced from plants was easily and logically explained:

> *No, but it is like this … chemically … it is like made up of … like the scientists have … it's like synthesised glucose … it's not like an apple that is taken directly from the tree … they have used the apple and made pastilles from the apples.*

---

[2] During the lessons, the teachers mostly used the word grape sugar. Grape sugar and dextrose are the same words in Swedish, and the students start to think about the dextrose pastilles when grape sugar is mentioned. Glucose, carbohydrates, sugar, grape sugar, fruit sugar, dextrose, etc. are words used during the lessons. In this chapter, we consistently use the word glucose when it is of little consequence for the context.

Sara mostly used linking-together reasoning with some memory reasoning. Her knowledge about photosynthesis and respiration was well developed. She was confident but went on talking in a way that sometimes muddled things up. She used scientific language and wanted to explain difficult processes. During the interview, there was a need to ask her to elaborate on her statements and to split some of her ‘big’ theories, like the whole plant life cycle, into smaller parts:

I: Why are the plants important?
S: *I mean, the plants create oxygen and humans need that … we need oxygen to live and if the plants wouldn’t be there we probably would have been created differently.*
I: How is the oxygen made?
S: *Hmm… that’s photosynthesis in these spruces and inside the vessels it’s created with like water and air and energy from the sun. Photosynthesis is created and the glucose comes out and at the same time oxygen comes too.*
I: Hmm when you say comes out what do you mean?
S: *Eh… actually we have talked about oxygen coming through the stomata on the leaves but I am not sure about the pine-needles and I really don’t know at all how the glucose comes out. Actually it could not come just like this out in the air, could it? I don’t know… we haven’t talked about that.*

The next excerpt on how respiration is related to the glucose in the plant shows the difficulty that students have connecting and understanding all facts that are presented in textbooks and by the teacher:

> *It burns…or it dissolves oxygen and carbon dioxide and water again so it gets like three different parts again. And the water the tree drinks up… no like… and then… I think that it has something to do with the bark/cortex and that it goes out through the bark or something… evaporates through the leaves or something maybe?*

Sara seemed to be confused but her answers to the follow-up questions showed that she could explain the concepts and how they were connected to the context. Sara was more confident than Jonas in explaining the scientific concepts and could easily recall the formula for photosynthesis or respiration (memory reasoning). However, she also faced more problems clarifying her thoughts than Jonas, since she was more bound to what the books and the teacher had said. Sara’s conceptual knowledge and reliance on the words of books and teachers characterise memory reasoning, as described in the next section.

Of all 23 interviewed students, there were 11 that mostly used linking-together reasoning. One memory and four school-weary reasoning students also partly used linking-together reasoning (see Fig. 6.1).

6.3.2.2 Memory Reasoning

Sune used memory reasoning and only with guidance did he realise that he had missed some crucial connections between concepts. He had, as he said, a good

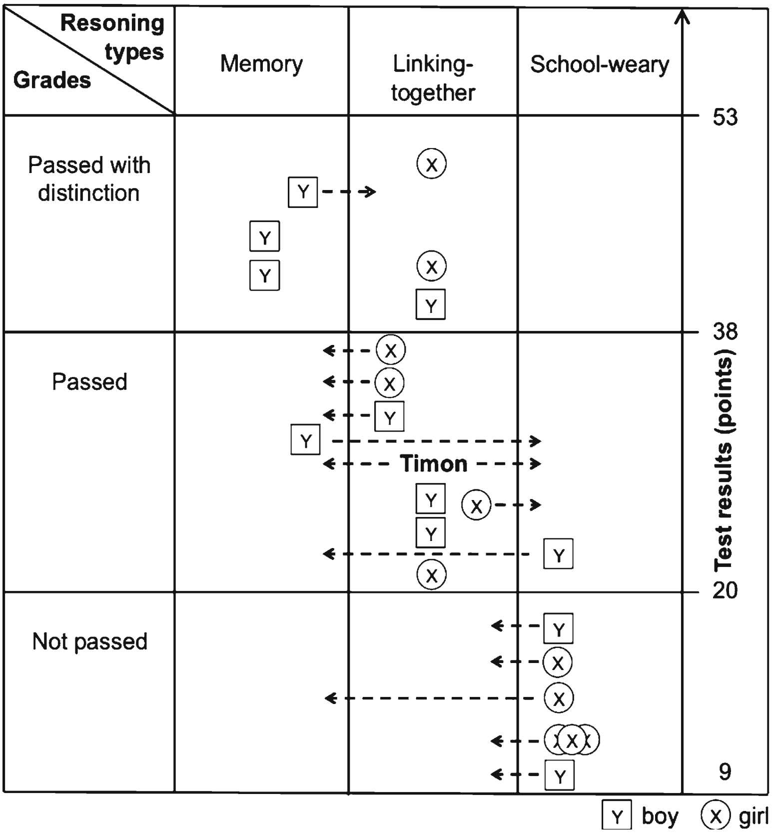


Fig. 6.1 Twenty-three students' use of reasoning types, their test results and grades

memory and his reasoning was characterised by memorised formulas and concepts. Nevertheless, he showed that he had understanding of processes involved in photosynthesis as illustrated by the following excerpt:

I: How can photosynthesis help to become this spruce twig?
S: *The spruce takes in* CO_2 *and* H_2O *and energy from the sun and transforms it into oxygen and glucose, where the glucose mostly is used to build up the trunk.*
I: Could you tell me more … it doesn't matter if you say something wrong.
S: *But it's like … water comes up through the roots and is transported in the trunk and the* CO_2 *gets in at the needles … at the stomata.*

Sune struggled with the question of where glucose was required in the body for a while before he concluded that he did not know. On the question 'What is respiration?', he gave a perfect account for the respiration formula but then claimed that he did not know where the respiration process took place. When he was told to think about the word, ‘cellular respiration’, genuinely surprised he said, ‘Is it in the cells?’ It is notable that Sune did not know that respiration is a cellular process. He also encountered problems when he was told to use his knowledge of photosynthesis to explain the creation of the potato. Of the 23 interviewed students, only four mostly used memory reasoning (see Fig. 6.1). Four students, who mostly used linking-together reasoning and two who mostly used school-weary reasoning, also partly used memory reasoning.

6.3.2.3 School-Weary Reasoning

Evelina said that she had no interest in science and that she had not understood the point in knowing or learning about ecology. Evelina was a weak performer in school and in the interview said that she did not know what to say as she knew practically nothing. When she was asked to say something about what she remembered from the whole ecology unit she mentioned the stomata that she had looked at with the microscope, and seeds and ecosystems were also mentioned. The researcher tried to make her talk about plants and what they need. At least three times, she answered that she did not know, but then suddenly said ‘You mean carbon dioxide and water that the plants need’, followed by an explanation about the products. She forgot the oxygen produced initially but easily stated it when she was asked about it. The ongoing discussion encouraged Evelina to talk and she showed some understanding of both photosynthesis and respiration:

I: Where is the sugar made before it comes to the apple?
E: *I don’t know.*
I: Yes you do.
E: *Yeah, but from the tree then….*
I: And where in the tree is it made?
E: *Is it in the roots?*
I: It is stored in the roots but in this case it is stored in the apple. Where is the glucose made?
E: *I don’t know…*
I: But you have told me before.
E: *No not where it is made, no…*
I: Where is the photosynthesis happening?
E: *But, in the plant.*
I: And … where about in the plant?
E: *I don’t know…*
I: Where did you say that the stomata were located?
E: *In the leaves. …is the sugar made in the leaves too?*

Evelina’s question of whether the sugar was made in the leaves showed how important it was to connect photosynthesis to living matter and to something concrete such as an apple or a branch. Evelina, just like Sune, did not realise where photosynthesis and respiration took place. Though they used two totally different ways of reasoning, they needed to engage in a discussion to better understand the processes.

Eight students mostly and three partly used school-weary reasoning (Fig. 6.1). It was difficult to interview these students as they constantly replied that they did not know the answer but during the interview they displayed some knowledge of the topics discussed.

6.3.2.4 Combination of All Three Reasoning Types

Timon was able to recall the concepts taught (memory) and he managed to link the concepts correctly (linking together), but he answered a question only when he wanted to (school weary). When he was asked to say something about the ecology unit, he skipped the ecology part and directly answered:

T: *Carbon dioxide and water and energy from the sun give glucose and oxygen.*
I: Was that what you remembered?
T: *That's just it. Photosynthesis…*
I: What is the glucose used for?
T: *Fruit, resin, cones and to give food. Because the plants eat it and then they grow. They grow because of the glucose but they also make cellulose, starch that is in bread, potatoes and trunks.*

Many of the students that used school-weary reasoning required a 'wheedling and enticing' way of interviewing to prevent them from getting bored; Timon was restless and bored after 5 min. His fast and often correct answers made the short 15-min interview substantial.

6.3.3 A Comparison of the Test Results and the Oral Reasoning

Figure 6.1 shows the diversity of the reasoning types used by the 23 interviewed students. Each student is categorised according to final test results and to the most dominant oral reasoning type. The arrows mark the other types of oral reasoning that the students used. The boys are marked with a square and a *Y*, and the girls are marked with a circle and an *X*. For example, Timon, the only student named in the figure, used mostly linking-together reasoning, and he received a passing grade. He also used memory and school-weary reasoning, and these are marked with two arrows.

Figure 6.1 shows that the students who used school-weary reasoning also used either linking-together or memory reasoning. Only one of the school-weary students passed the test. School-weary students who used memory reasoning, for example, the school-weary boy (*Y*) who passed the test, succeeded better in test than those who used their own explanations and made efforts to link together ideas. Students who used linking-together reasoning often showed better understanding during the interview than in test. These students tried to put everything in a context and they wanted to explain everything. This strategy often made them speculate and develop their own theories, a strategy that was not successful when taking the test. The students who used linking-together reasoning and succeeded well in the test reasoned sparingly and did not speculate. Some students, who used memory reasoning, could give correct definitions and scored high in the test. However, they showed surprising gaps when they tried to explain the relationship between concepts in the interviews.

The students revealed much more understanding about photosynthesis and respiration during the interviews than in the written test. All 23 students managed to orally explain the process of how photosynthesis works, but many of them needed some guidance to explain the process of respiration. Jonas used linking-together reasoning, and his knowledge served him better in the interview than in the test. Sara's oral explanation was characterised by high concept knowledge that she always tried to put into a context. Her reasoning lost focus in the written questions, and she only got a passing grade in the test. Even so, there were students who only used linking-together reasoning and succeeded well in the test, for example, the female student who obtained the highest marks in the test (Fig. 6.1). She reasoned more sparingly than Sara and did not speculate. This girl's closest male equivalent was the one who explained ecology processes most fluently but he used more memory than linking-together reasoning. Sune's memory reasoning with short and correct answers (often written formulas) was rewarded in the test, and he received a pass with distinction grade. Evelina did not pass the test, but in the interview she showed that she had more knowledge and understood better that what her test result indicated. There were only two students who, from their oral reasoning, could be categorised as weak achievers, and they partly used memory reasoning.

6.4 Discussion

According to the literature, learning and understanding photosynthesis and respiration is difficult (Andersson 2008; Driver et al. 1994; Smith and Anderson 1984). An essential question is whether it is possible to judge the understanding of a student from an answer in a written test. In this study, Timon's answers in the three essay questions indicated that he had understood photosynthesis. Why did Timon not answer the Polar bear question and why did he not elaborate his answer in the Terrarium question? In his written answer, the respiration process was correctly explained, but, contradictory to his oral reasoning, he wrote that respiration only happens in plants.

The students in this study took part in an ecology unit for about 10 weeks, and their written tests showed that they increased their knowledge of photosynthesis and respiration more than expected, when compared to results from the study by Özay and Öztas (2003). The students also showed greater knowledge of both concepts than students in the NE and in the study by Driver et al. (1994). Their written reasoning confirmed better knowledge in photosynthesis than in respiration which may be attributed to the two teachers' greater focus on plants than animals during the ecology unit.

In the comparison with the NE (1992, 2003), the pre-test results in this study also showed that the students had much better knowledge about photosynthesis than the students in the NE. The large national and international evaluations (NE, PISA and TIMSS) which present students' understanding about photosynthesis and respiration without any connection to the ongoing teaching and the classroom context may not adequately measure students' actual knowledge. A long time could have passed since the content was learned, students may have difficulties interpreting the questions or the students may not be motivated to answer adequately and correctly in these large surveys. Questions or tests connected to the ongoing teaching in the classrooms are a fairer way to evaluate students' knowledge.

Most of the students demonstrated deeper knowledge in the guided interview compared to the written test. The interviewed school-weary students managed to link the concepts, and they would have passed in an oral test. All of the 23 interviewed students showed adequate understanding of photosynthesis. But there were also students with good memory and high grades in the test that showed surprising gaps in understanding when they had to orally explain the formulas and put them in a context. One of the boys who used memory reasoning and succeeded quite well in the test did not remember anything in the interview 2 weeks later. The students who succeeded best in the interviews tried to put everything in a context, and they wanted to explain everything. Unfortunately, these students often speculated and developed their own theories that were not acceptable in the test. The traditional test situation in schools does not include the presence of a conversational partner, and without that, the text of the problem can be difficult for the students to understand. The conversational partner can help the students to resolve difficulties of a conceptual nature. Schoultz et al. (2001) concluded that the low performance on written tests appears to be a product of the absence of the oral communicative format. Results of this study add strength to the importance of a conversational partner to assess students' understanding.

A chemical formula of photosynthesis or respiration interested a few students, but the complex explanation about how a carrot, potato or an apple 'comes out of' photosynthesis made all 23 teenagers more interested in the difficult processes. This kind of more complex reasoning during the interview made both high and low achieving students more interested in knowing more about the life cycle of plants. This corresponds with the findings of Delpech (2002), who asked for more everyday examples to be included in teaching and to allow more flexibility in the students' reasoning, like speculations and wondering questions beyond the content of the lesson or the textbook. The low achieving students in this study asked for emotional aspects, like ethical and practical dilemmas, in the lessons, to make it more interesting. During the interview, these students started to show their actual knowledge about plants when they realised the importance of plants to life. This is in line with Slingsby and Barker (2003) who claimed that biology teaching need to equip the students with ethical and emotional aspects to learn social and scientific skills.

6.4.1 Conclusion

Written tests alone may not give an adequate indication of students' understanding of science; students need to be given opportunities to be assessed orally as well to clarify what the questions mean and explain their understandings. Developing a deep understanding of photosynthesis and respiration may not be as unattainable as indicated by international surveys if students are given the opportunity to reason with their teachers and classmates and, when using chemical formulas, to connect them to concrete material, such as branches and fruits. This corresponds to learning theories that argue for both everyday language and scientific language as essential for a deeper understanding of science.

Appendix

(*Ecology test in the eighth grade – only contains the questions with a content of photosynthesis and respiration)*

2. Karin fills up a plastic bag with usual air (air is a mixture of gases). Then she puts the plastic bag over the potted plant and ties it round the stem as shown in the figure below. The seal is fully airtight. The plant is put in darkness for a whole night. The following are some statements about what happens to the air mixture in the plastic bag. You are going to put an *R* after a right statement and an *F* after a false statement. 1*p* (*p* = scores in the test):

(a) The amount of oxygen increases
(b) The amount of oxygen decreases
(c) The amount of oxygen stays the same
(d) The amount of carbon dioxide increases
(e) The amount of carbon dioxide decreases
(f) The amount of carbon dioxide stays the same

7. (a) What is the process in which the green plants capture light called? 1*p*
   (b) Why do raspberries that get more sun light taste sweeter than the ones that have been in the shade? 2*p*
   (c) What is the green pigment in plants called? 1*p*
8. You have an elodea plant in a test tube beneath a shining lamp. What gas comes like bubbles from the plant? 1*p*
9. A small tree is planted on a meadow. Twenty years later, it has grown into a big tree. The tree has grown taller and the trunk has grown thicker. The tree has many leaves, branches and big roots. The tree weighs 250 k more than when it was planted. Where do these 250 k come from? Explain your answer as fully as possible. 3*p*
10. (a) Describe respiration. Please draw to support your explanation. 2*p*
    (b) Does respiration take place in both plants and animals? Explain. 2*p*
11. What purpose do decomposers serve in the ecosystem? 2*p*
17. In the exhalation air from a polar bear on Greenland, there are molecules of carbon dioxide. We are interested in the carbon atom in one of these molecules. Many years later, this special carbon atom is found again in the front paw muscle of a young wolverine in the Swedish mountains. Describe as carefully as possible the carbon atom's journey from the polar bear to the wolverine's paw. 4*p*
18. Why are there so few top-level predators in an ecosystem compared to plants? Explain as carefully as you can. 3*p*
19. Use the figure and explain the oxygen and carbon cycles in nature. Please draw arrows that elucidate your description. Use the following words: oxygen, fox, hare, water, carbon atom, grass, respiration, air, glucose, carbon dioxide and decomposers. 4*p*



20. You take a glass jar with a lid and put some soil in it. Soil usually has fungus and bacteria in it. You plant some green plants and add water to get humidity. Then you put on the lid and put the jar in a lit place. What will happen in the jar if it is standing there for 5 years without opening the lid. 4*p*

References

Andersson, B. (2008). *Att förstå skolans naturvetenskap. Forskningsresultat och nya idéer [To understand school science. Research findings and new ideas]*. Lund: Studentlitteratur. Elanders Hungary Kft

Andersson, B., Bach, F., Frändberg, B., Jansson, I., Kärrqvist, C., Nyberg, E., et al. (2009). *NORDLAB. Formativ utvärdering med fotosyntes som exempel [Formative assesment with photosynthesis as an example]*. http://na-serv.did.gu.se/NORDLAB/se/trialse/pdf/bi3.pdf. 12 Mar 2012.

Barak, J. (1999). As 'process' as it can get: Students' understanding of biological processes. *International Journal of Science Education, 21*, 1281–1292.

Barker, S., & Slingsby, D. (1998). From nature table to niche: Curriculum progression in ecological concepts. *International Journal of Science Education, 20*, 479–486.

Bogdan, R. C., & Biklen, S. K. (2003). *Qualitative research for education. An introduction to theories and methods* (4th ed.). Boston: Allyn & Bacon/Syracuse University.

Canal, P. (1999). Photosynthesis and 'inverse respiration' in plants: An inevitable misconception? *International Journal of Science Education, 21*, 363–371.

Carlsson, B. (1999). *Ecological understanding – A space of variation*. Thesis of Luleå University of Technology.

Delpech, R. (2002). Why are school students bored with science? *Journal of Biological Education, 36*, 156–157 (editorial).

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary school science: Research into children's ideas*. London: Routledge.

Driver, R., Leach, J., Millar, R., & Scott, P. (1996). *Young people's images of science*. Buckingham/Philadelphia: Open University Press.

Erickson, F. (1986). Qualitative methods in research on teaching. In M. C. Wit-trock (Ed.), *Handbook of research on teaching* (3rd ed., pp. 119–161). New York: Macmillan.

Feinsinger, P., Margutti, L., & Oviedo, R. D. (1997). School yards and nature trails: Ecology education outside university. *Trends in Ecology & Evolution, 12*(3), 115–119.

Helldén, G. (1992). *Grundskoleelevers förståelse av ekologiska processer [Compulsory students understanding of ecological processes]*. (Studia Psykologica et Pedagogica. Series Altera C). Stockholm: Almqvist & Wiksell.

Helldén, G. (2005). Exploring understandings and responses to science: A program of longitudinal studies. *Research in Science Education, 35*, 99–122.

Hogan, K., & Fisherkeller, J. (1996). Representing students thinking about nutrient cycling in ecosystems. *Journal of Research in Science Teaching, 33*, 129–141.

Kvale, E. (1996). *Interviews. An introduction to qualitative research interviewing*. London/New Delhi: Sage.

Magntorn, O. (2007). *Reading nature. Developing ecological literacy through teaching*. Norrköping: The Swedish National Graduate School in Science and Technology Education, Linköping University.

Magntorn, O., & Helldén, G. (2007). Reading nature from a 'bottom-up' perspective. *Journal of Biological Education, 41*(2), 68–75.

Marmaroti, P., & Galanopoulou, D. (2006). Pupils' understanding of photosynthesis: A questionnaire for the simultaneous assessment of all aspects. *International Journal of Science Education, 28*, 383–403.

Mortimer, E. F., & Scott, P. (2003). *Meaning making in secondary classrooms*. Milton Keynes: Open University Press.

Näs, H., & Ottander, C. (2008). Students reasoning while investigating plant material. *NORDINA-Nordic Studies in Science Education, 2*, 177–191.

Näs, H., & Ottander, C. (2009). The space shuttle – An introduction to ecology teaching. In M. Hammann, A. J. Waarlo & K. Boersma (Eds.), *The nature of research in biological education; Old and new perspectives on theoretical and methodological issues*, (pp. 297–311). Utrecht: The Netherlands.

National evaluation of the compulsory school in 1992 and 2003. http://www.skolverket.se/ (20091004)

Özay, E., & Öztas, H. (2003). Secondary student's interpretation of photosynthesis and plant nutrition. *Journal of Biological Education, 37*, 68–70.

Schoultz, J., Säljö, R., & Wyndham, J. (2001). Conceptual knowledge in talk and text: What does it take to understand a science question? *Instructional Science, 29*, 213–236.

Slingsby, D., & Barker, S. (2003). Making connections: Biology, environmental education and education for sustainable development. *Journal of Biological Education, 38*, 4–6 (editorial).

Smith, E. L., & Anderson, C. W. (1984). Plants as producers: A case study of elementary science teaching. *Journal of Research in Science Teaching, 21*, 685–698.

Swedish National Agency for Education. (2009). *Compulsory school. Syllabuses: Science studies.* Retrieved October 8, 2009, from http:www3.skolverket.se

The Swedish Research Council. (2002). *Ethical guidelines for research*. Vällingby: Elanders Gotab.

Vikström, A. (2005). *A seed for learning. A variation theory study of teaching and learning in biology.* Doctoral thesis no: 2005:14, Department of Educational Sciences, Luleå University of technology.

Vikström, A. (2008). What is intended, what is realized, and what is learned? Teaching and learning biology in the primary school classroom. *Journal of Science Teacher Education, 19*, 211–233.

Wood-Robinson, C. (1991). Young people's ideas about plants. *Studies in Science Education, 19*, 119–135.

Chapter 7
Introducing Students to Authentic Inquiry Investigation Using an Artificial Olfactory System

Niwat Srisawasdi

7.1 Introduction

The history of science can be considered to be an account of the development of scientific knowledge about the physical world that has been acquired through the spirit of human inquiry for thousands of years. Corresponding with this human endeavor, scientific inquiry plays a vital part in the growth of science advancement and is also regarded as a critical instructional strategy in efforts to reform science education. Contemporary reforms in science education have recommended using scientific inquiry as a context for learning science to develop scientific literacy and thinking skills (American Association for the Advancement of Science 1993, 1998; National Research Council 2000; Olson and Loucks-Horsley 2000). Particularly, improving understanding of the nature and process of scientific inquiry has become one of the most important goals in the field of science education (Abd-El-Khalick 2005; Abd-El-Khalick et al. 1998, 2004; Duschl 1990; Hodson 1988; National Research Council 1996).

Recent research has indicated that the structural mode (highly structured labs that provide questions, theory, and experimental and analytical procedures) of inquiry is not sufficient for developing scientific thinking (Zion 2006; Zion et al. 2004; Zion and Sadeh 2007). This type of investigation produces a robotic style of thinking that is less effective than teaching deductive reasoning, detailed in-depth thought processes, and logic. The classroom form of inquiry consists of simple demonstrations or illustrations of previously presented scientific facts, or simple observations and experiments that are distant from authentic inquiry practices in contemporary scientific research. This situation may prevent students from obtaining valuable scientific experiences from the inquiry process. This may also perpetuate

---

N. Srisawasdi (✉)
Division of Science, Mathematics, and Technology Education, Faculty of Education,
Khon Kaen University, Khon Kaen, Thailand
e-mail: niwsri@kku.ac.th

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_7,

the idea of science as a foreign thing, with minimal opportunities to relate to socio-cultural factors, economic milieu, and importance of solving specific scientific problems. There is a definite need to improve scientific inquiry activities by incorporating more features of authenticity (Bruck et al. 2008; Chinn and Hmelo-Silver 2002; Chinn and Malhotra 2002; Gengarelly and Abrams 2009; Wong et al. 2008).

In authentic inquiry practices, students need to determine a scientific question to investigate, consider how to investigate the question based on existing scientific theories and background, determine what data to collect, decide how to interpret that data, discuss the results, create the best way to present that data, and then draw inferences from the data. The teacher plays a role in providing the necessary framework for investigation while encouraging students to pose questions and conduct investigations independently. This situation creates a community of inquiry where teachers and students learn by collaboration and interaction with each other (Lim 2004; Zion and Slezak 2005).

7.2 Scientific Inquiry in a Computerized Laboratory Environment

Computer technology is so commonplace in the practice and advancement of science (Waight and Abd-El-Khalick 2007) that it has become an essential tool with the potential to dramatically enhance the output and productivity of researchers. Generally, scientists utilize computer technology in the laboratory for data gathering, storage, analysis, simulating, modeling, and facilitating the automatic control and sharing of instrumentation. Thus, a potential way to more closely simulate the nature of actual scientific research and increase authenticity in educational scientific inquiry practice is to incorporate computerized laboratory environments (Settlage 1995; Sokoloff and Thornton 1997; Thornton and Sokoloff 1990). This type of learning environment could transform the way science is taught by fostering inquiry (Cox and Webb 2004; Edelson 1998, 2001; Maor and Fraser 1996), helping students to investigate, observe, collect, exchange, analyze, and interpret scientific data, as well as to facilitate modeling of scientific principles (Kim et al. 2007). The computerized laboratory environment is advantageous in that it provides students with substantially more opportunities to construct an independent understanding of physical phenomena and scientific principles, (Krusberg 2007; McRobbie and Thomas 2000; Nakhleh and Krajcik 1994), acquire scientific inquiry skills (Friedler et al. 1989, 1990; Mistler-Jackson and Songer 2000; Songer 1998), and increase motivation and confidence in learning science (Clark and Jackson 1998).

7.3 Self-Regulation in Inquiry-Based Science

In an extended open inquiry setting that gives students the opportunity to conduct their own independent investigations, self-regulated learning opportunities are significant (Tytler 1992). This is the case particularly in the context of a computerized learning environment that allows for a high degree of learner control and provides possibilities for self-directed learning (Winters et al. 2008). The authentic inquiry environment, compared with traditional classroom laboratory settings, demands new roles and responsibilities from students and teachers alike. The teachers guide the student activities and facilitate the organization of the area of study (Schwartz and Crawford 2006; van der Valk and de Jong 2009). In this environment, students are challenged to work independently and must endeavor to develop their own control and regulatory mechanisms to achieve success (Pintrich 2000). From a social cognitive perspective, the processes of self-regulation emerge dynamically in three cyclical phases: (1) the forethought phase, including processes that precede learning efforts but are designed to enhance such performance, and sources of self-motivation that empower this self-initiated form of learning; (2) the performance phase, including self-control strategies and a form of self-observation that works to enhance the quality and quantity of one's performance; and (3) the self-reflection phase, including self-judgment and self-reaction to one's performance (Zimmerman and Tsikalas 2005).

Whether students are afforded great freedom in regulating their own learning, as in the case of truly open-ended learning environments, the need to provide instructional support is critical (Hannafin and Scott 2001). The use of scaffolding is increasing in educational design as it assists learners in accomplishing their independent tasks and enables them to learn from open-ended experience (Reiser 2004). Particularly, the process of scaffolding students' self-regulation during learning with computer-based learning environments has recently received a tremendous amount of attention from researchers in several communities (Azevedo and Hadwin 2005). When providing instruction in a truly open-ended learning environment, Hill and Hannafin (2001) have identified embedded conceptual, metacognitive, procedural, and strategic scaffolds that teachers can use to assist students in understanding essential ideas and theories, monitoring their learning processes and reducing cognitive overload, and structuring their tasks and finding alternative strategies to solve problems. Additionally, Quintana et al. (2004) proposed scaffolding design frameworks for software based around three constituent processes of inquiry learning. First is the scaffolding of sense making that involves the basic operations of testing hypotheses and interpreting data. The second is the scaffolding of process management, which involves the strategic decisions required in controlling the inquiry process. The third is the scaffolding of articulation and reflection, which is the process of constructing, evaluating, and articulating what has been learned.

7.4 Methods

7.4.1 Participants

The participants of this study consisted of 16 secondary school students studying in Thailand who were enrolled in a science project course. The course, which was regularly taught by three science teachers, placed an emphasis on enhancing "real science" inquiry skills by participating in this study and conducting an experimental project with the students. Thus, the students were selected purposively based on the particular objectives of the course and their willingness to participate in the study. The students were in the Grade 12, aged 17–18 years, and the group was composed of 11 males and five females. It was determined via examination of the school curriculum and from feedback from the teachers that none of the students had any experience with computerized laboratory experimentation. However, the participants did have satisfactory basic computer skills. The students were divided randomly into two groups of eight each and given an opportunity to conduct their own investigation.

7.4.2 The E-Nose Technology Project

The Electronic Nose Technology (E-Nose) originated in the late 1980s, from the concept of developing highly specific sensors and methods for identifying unique substances. The E-Nose emerged as an artificial sensorial system that mimics the human odor recognition mechanism. It is able to detect and discriminate complex odors using sensor arrays. The development of this artificial olfactory system occurred in a contemporary area of scientific and technological research on artificial intelligence systems. This research has led to a variety of practical applications and new possibilities in areas such as the food and beverage industry, perfumery, biotechnology, medicine, chemistry, and environmental sciences. Supported by the National Electronic and Computer Technology Center (NECTEC) in cooperation with Center of Intelligent Materials and System (CIMS), Mahidol University, and the Thailand Research Fund (TRF) in cooperation with Office of the Higher Education Commission, the artificial olfactory system was produced with multiple purposes. The first was to mimic the human olfactory system to aid in studying flavor recognition. Another was to create an interactive computer-based laboratory tool to promote active learning of science, to allow students to experience authentic scientific research and practice. The technological affordance for experimenting with the artificial olfactory system was divided into three areas as follows.

7.4.2.1 Physical Affordance

The artificial olfactory system was constructed to mimic the human olfactory system. It has a nasal cavity, an oral cavity, and an oro- and nasopharynx with a sensing device that incorporates a gas sensor array and a dynamic airflow system. The model was made of polycarbonate material making it easy to use, transparent, and robust. It was also designed to be portable and could be assembled easily in a short time to perform experiments. The schematic diagram of the system is given in Fig. 7.1.

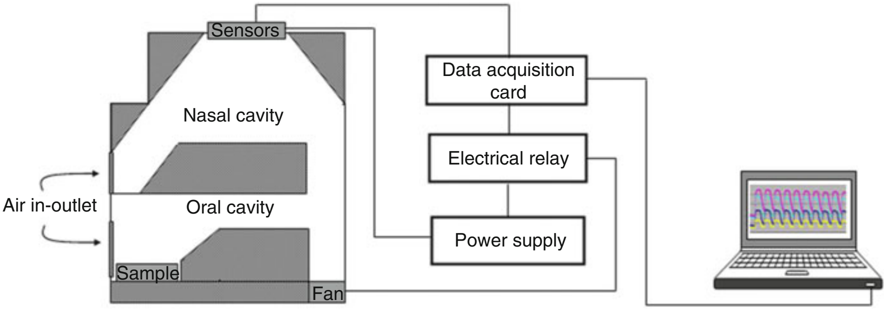


Fig. 7.1 Schematic diagram of the hardware for the artificial olfactory system

7.4.2.2 Digital Affordance

The acquisition of experimental data and control of the airflow system were programmed using the Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW). The user interface in the LabVIEW environment was designed to provide a simple interaction between user and software and consists of three components: (1) a monitor panel which provides a simultaneous display of electrical resistance changes corresponding to a sample flavor test; (2) a control panel for controlling experimental parameters such as the number of iterations, timing of air inflow for simulated inhalation and air outflow for simulated exhalation, and the interval between inhalation and exhalation; and (3) a learning and training panel which provides scaffolding for the inquiry process. The system also provided students with an automated method of observation and data storage, which could reduce perceptual bias that can occur with other methods of observational data collection. Through the use of electronic equipment and programmed, automatic data storage, the observation process was automated and the data organized by statistical procedures as in authentic scientific research. The user interface is displayed in Fig. 7.2.

7.4.2.3 Pedagogical Affordance

A scaffolding design framework by Quintana et al. (2004) for inquiry-based software was used to create components of the software interface of the artificial olfactory system. The framework suggested organizing scaffolding around three constituent processes for inquiry: sense making, process management, and articulation and reflection. With regard to sense making, tools for organizing visual conceptual such as concept mapping, macroscopic representations, and microscopic representations were implemented to help users understand scientific and related technological knowledge. In the process management constituent, flow charts were used to facilitate and guide experimentation. In the process of articulation and reflection, an inquiry

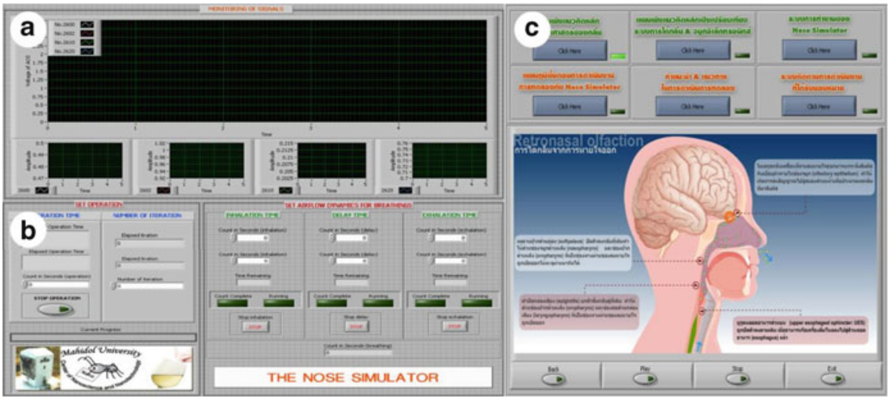


Fig. 7.2 Graphical user interface of the software for the artificial olfactory system. (**a**) The monitor panel. (**b**) The control panel. (**c**) The learning and training panel

task manager was used to monitor the completion of the experiments in the laboratory and to point out the necessary details for inquiry tasks.

7.4.3 Procedure

The students experienced authentic inquiry processes by performing their own experiments with the artificial olfactory system. There were three phases in the learning activity. The first phase involved an introduction to the science of smell and a brief orientation on the artificial olfactory system. In the second phase, both groups independently conducted odor classification experiments over a period of two weeks in the science laboratory at their school. The students were instructed to generate the topic of their own investigation. They crafted their own questions for the experiment and subsequently designed procedures to collect, analyze, and interpret the experimental data, and to communicate the results of their investigation. In the third phase, which focused on statistical analysis, the students worked with the assistance and guidance of the teacher to analyze the experimental data using principal component analysis (PCA) – a useful statistical technique for reducing uncorrelated data and for finding patterns in large unorganized data sets. The students also had to scrutinize their experiments and identify any experimental errors to ensure that their data were correct, precise, and accurate. Notably, assistance was only given in the last session as required by the students. Following completion of the investigation, a questionnaire was administered to the students to explore their perceptions of the artificial olfactory system. There were 20 questions and four scales (cognitive performance, scientific inquiry skills, emotional practice, and social inquiry process) on the questionnaire, and each item rated the students’ perceptions of the artificial

Table 7.1 Scale description and sample item for each scale of the questionnaire

Scale	Description	Sample item
Cognitive performance	Extent to which students made the effort to think during experimentation	Experimenting with the artificial olfactory system helped me learn to process information in a scientific study to achieve my research aims
Scientific inquiry skills	Extent to which student performed the experiments	Experimenting with the artificial olfactory system gave me opportunities to select and control experimental variables and other relevant conditions for conducting a scientific investigation
Emotional practice	Student feelings about the experimentation	Experimenting with the artificial olfactory system enables me to develop a sense of curiosity about science
Social inquiry process	Extent to which students communicated and negotiated during the experiments	Experimenting with the artificial olfactory system encouraged members in the group to communicate and propose scientific ideas for the experiment

olfactory system using a six-point scale ranging from "never" (0 points) to "very much" (5 points). A description of the questionnaire, as well as sample items from each of the four scales, is provided in Table 7.1.

Ten students volunteered to participate in a semistructured interview two weeks after the last session to investigate their attitude toward authentic inquiry investigation with the artificial olfactory system. There were six open-ended questions in the interview (see Table 7.6). Descriptive statistics and protocol analysis were used to process the students' responses from the questionnaire and the interview, respectively.

7.5 Results

7.5.1 *Students' Responses on the Perception Questionnaire*

Students' perceptions of experimentation with the artificial olfactory system are summarized in Tables 7.2, 7.3, 7.4, and 7.5. Table 7.2 shows the means of the items on the cognitive performance scale. The means of items 1 and 2 are close, 4.41 and 4.35, respectively, indicating that students felt that they mostly achieved their learning goals by experimenting with the artificial olfactory system. This suggests that the artificial olfactory system provided a learning environment that was conducive to conceptualizing scientific information and managing practical procedures.

Table 7.2 Item means and summary responses on the cognitive performance scale

Item statements	Mean	Description
1. Helped them learn to process information from the study to achieve their research aim	4.41	Satisfactory
2. Gave them control over the practical work for achieving that aim	4.35	Satisfactory
3. Encouraged them to conduct other scientific studies	4.18	Satisfactory
4. Gave them a sense of causality in the nature of scientific practice	4.12	Satisfactory
5. Afforded them the construction of meaning from related science and technological knowledge	3.94	Satisfactory
Overall mean average	4.20	Satisfactory

Table 7.3 Item means and summary responses on the scientific inquiry skills

Item statements	Mean	Description
1. Selected and controlled experimental variables and relevant conditions for conducting a scientific investigation	5.0	Extremely satisfactory
2. Performed calculations and interpreted trends and patterns of data to draw conclusions	5.0	Extremely satisfactory
3. Developed scientific explanations and models through discussions, debates, and experimental evidence	4.94	Extremely satisfactory
4. Identified possible sources of error (e.g., procedural and management) and appropriate controls (repeated trials)	4.88	Extremely satisfactory
5. Formulated a testable hypothesis based on prior knowledge and experience	4.65	Extremely satisfactory
Overall mean average	4.89	Extremely satisfactory

Table 7.4 Item means and summary responses on the emotional practice scale

Item statements	Mean	Description
1. Created positive interest in and desire toward additional scientific studies	4.94	Extremely satisfactory
2. Made learning science more enjoyable and fulfilling	4.82	Extremely satisfactory
3. Gave them satisfaction while learning and doing scientific experiments	4.59	Extremely satisfactory
4. Gave them self-confidence while conducting scientific experiments	4.41	Satisfactory
5. Developed a sense of curiosity about science	4.18	Satisfactory
Overall mean average	4.59	Extremely satisfactory

The students were encouraged to understand experimental and procedural information, and to make sense of the data that they obtained. Items 3 and 4 were given close scores, 4.18 and 4.12, respectively. This indicates that experimenting with the artificial olfactory system mostly encouraged the students to create their own experiment and think scientifically and also encouraged them to understand the relationship between cause and effect in science. Item 5 obtained the lowest mean score, 3.94, which suggests that experimenting with the artificial olfactory system

Table 7.5 Item means and summary responses on the social inquiry process scale

Item statements	Mean	Description
1. The teacher provided guidance and assistance to the students	4.76	Extremely satisfactory
2. Actively participated in a group working on the experiment	4.59	Extremely satisfactory
3. All steps and procedures were followed by all the group members	4.53	Extremely satisfactory
4. All steps and procedures of the experiments were acceptable to group members	3.94	Satisfactory
5. Working with the Artificial Olfactory System facilitated group communication which contributed to scientific ideas about the experiment	3.82	Satisfactory
Overall mean average	4.33	Satisfactory

adequately helped students to make sense of scientific and technological knowledge in the area being studied. Overall, the odor classification experiment was seen as mostly favorable by the students, as revealed by the average scale mean score of 4.20 out of 5.0. This score suggests that students perceived a relatively high degree of cognitive engagement during the laboratory experimentation.

Table 7.3 shows the means of the items on the scientific inquiry skills scale. The means of items 1 and 2 were both scored 5.00, showing that experimenting with the artificial olfactory system greatly scaffolded students in the controlling of variables and manipulating of parameters, and helped them in drawing logical conclusions based on statistical analyses. The scores of items 3 and 4 were 4.94 and 4.88, respectively, which implies that the experimental task enhanced students' skill set in the construction of experimental explanations and mental models, which then contributed to the discussion and debate about the experimental evidence. It also appears that the experimental task supported students in dealing with errors and uncertainty in the data. The students were able to integrate conceptions of experimental errors and possible sources thereof into their scientific reasoning. Item 5 had a mean score of 4.65. This suggests that students were able to use their prior knowledge and experience to formulate hypotheses that could be precisely investigated. Overall, on the scientific inquiry skills scale, the average scale mean score was 4.89, implying that the laboratory experiments were able to enhance students' scientific inquiry skills.

Table 7.4 shows the means of the items on the emotional practice scale. Item 1 had the highest mean score of 4.94, suggesting that students were very interested in doing additional scientific studies. The second item had a mean of 4.82, which indicated that the students experienced positive feelings when they were doing the experiments. This is consistent with the score on item 3, a mean of 4.59, which suggests that students are very satisfied with their learning and engaging in experiments with the artificial olfactory system. Item 4 had a mean rating of 4.41, which indicated that students experienced success with the learning tasks and that they felt confident with science experimentation. Item 5 obtained a mean score of 4.18. This suggests that experimenting with the artificial olfactory system fostered a sense of scientific curiosity. Overall, the students seemed to derive enjoyment from working experiments, as indicated by the average scale mean score of 4.59.

Table 7.5 shows the item means on the social inquiry process scale. Item 1 had the highest mean, 4.76, which indicated that the teacher was able to provide the necessary assistance and guidance to the students in the experiments. The second and third items had scores of 4.59 and 4.53, respectively, which suggest that the students felt that they were given the opportunity to actively participate in the experiment and that all of the group members paid careful attention to the experimental procedures. The fourth and fifth items had mean scores of 3.94 and 3.82, respectively, suggesting that the experimental design and planning process were moderately acceptable for all members of the group and that the learning task was able to enhance students' communication skills within their work group. Overall, the average mean score of 4.33 on the social inquiry process scale indicated that students perceived that they had participated meaningfully in collaborative inquiry during the group experimentation.

7.5.2 Students' Responses on the Individual Interview

Semistructured interviews provided more feedback about students' attitudes toward authentic inquiry with the artificial olfactory system. The results of the categorization of students' answers to the open-ended questions and the percentage of the students who provided such answers are reported in Table 7.6.

Students indicated when answering question 1 that they acquired a new body of scientific and technological knowledge. This included an understanding of the biological mechanisms of smell and the mechanism of the electronic nose. In addition, the student responses indicated that they felt they had increased their scientific skills by doing the experiments. They also stated that they had learned how to use advanced statistics to analyze experimental data and to draw conclusions from the statistical data. Students said that they had the opportunity to collaborate in groups and to learn about and explain scientific models with the aid of experimental evidence. The findings of the questionnaire indicated a positive attitude toward scientific studies and an interest in and eagerness to experiment with the novel artificial olfactory system. In response to question 2, students mentioned that they had the opportunity to perform interesting scientific experiments such as the classification of different odorants. They also stated that they had been able to collaborate and share ideas with the other members of the group, and that this process had brought out rich ideas contributing to the success of the experiments. The students appreciated the opportunity to design and conduct their own experiments and to work with a modern scientific instrument. However, they wanted more time to conduct their experiments so that they could collect more data for addressing their research questions. They also suggested that there be more teacher discussion and elaboration on the science and technology involved in the experiments and tools to help them understand more deeply the concepts involved.

Table 7.6 Summary responses of the students from individual interview conducted

Interview questions	Students' responses
1. What did you get from experimenting with the artificial olfactory system?	1. Acquired new body of scientific and technological knowledge (80%) 2. Increased scientific skills by doing the experiments (70%) 3. Learned to use advanced statistics for analysis of experimental data (50%) 4. Learned to explain a scientific model using experimental evidence during group discussions (80%) 5. Gained a positive attitude toward scientific studies (60%) ("before, we felt bored and had no interest in science experiments")
2. What did you find most satisfying about inquiry investigation with the artificial olfactory system?	1. Had a chance to conduct an interesting scientific experiment (50%) 2. Had the opportunity to share ideas with other members of the group (60%) 3. Had an opportunity to design and conduct our own experiment (40%) 4. Had the chance to work with a modern scientific artificial olfactory system (60%)
3. What should be improved on experimental investigation of odor classification with the artificial olfactory system?	1. Give more time in doing/conducting the experiment (40%) 2. More elaborations and discussions about artificial olfactory system to help us more clearly and more deeply grasp the concepts involved (40%)
4. What did you find most satisfying about the artificial olfactory system device?	1. Interacting with the interesting screen interface (80%) 2. Provided guidance for practical works (70%) 3. Ease of use of the device – user friendly (30%) 4. Easy to understand the directions/instructions because of the diagrams given (60%)
5. What improvements should be made to the artificial olfactory system device?	1. The device should have a mode to eliminate the odorants faster (20%)
6. What do you want from working with the artificial olfactory system experiment in the future?	1. Conduct more experiments with other odorants (70%) 2. If possible, to integrate the experiment with a topic in school science to further understand the artificial olfactory system and the related scientific inquiry process (40%)

The students expressed that they were satisfied with the interesting screen interface of the artificial olfactory system device. They also added that the system was easy to use because of the user-friendly instructions provided. Based on their experience with artificial olfactory system experiments, the students suggested improving the artificial olfactory system device so that it could eliminate odorants faster. This would reduce the time spent waiting between trials for the system to eliminate the odorants from the previous trial. In response to item 6, the students suggested that they be given opportunities to conduct more experiments with other odorants. They also suggested that the E-Nose technology be included in their school science curriculum so that they could better understand the technology involved and the benefits that it could offer.

7.6 Conclusion

The survey and interview data collected in this study have succeeded in demonstrating the value of using collaborative authentic inquiry activities aided by technology for learning science. In experimenting with an artificial olfactory system, students were able to learn new concepts and improve their scientific inquiry skills while engaging in authentic and sophisticated scientific research. While this learning experience was scaffolded by the teacher and a well-designed artificial olfactory system, the students were able to work collaboratively to plan, implement, and monitor their investigations. Students also learned to interpret and draw scientific conclusions from statistics, find trends, and identify possible errors. Experimenting with the artificial olfactory system provided students with the opportunity to glimpse the complex nature of scientific research, as well as encouraging an understanding of the functions and applications of scientific inquiry. Thus, authentic and contemporary inquiry activities in a computer-based laboratory environment have great potential for helping students learn science in a meaningful and effective way. This chapter also demonstrated the transformation of a tool used in modern science and technology research to become a tool intended to teach scientific inquiry in the classroom. This process could be viewed as a developmental approach to using knowledge in contemporary science and technology research to develop innovative instructional materials for science and technology education.

References

Abd-El-Khalick, F. (2005). Developing deeper understandings of nature of science: The impact of a philosophy of science course on preservice science teachers' views and instructional planning. *International Journal of Science Education, 27*(1), 15–42.

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education, 82*, 417–436.

Abd-El-Khalick, F., BouJaoude, S., Duschl, R. A., Hofstein, A., Lederman, N. G., Mamlok, R., et al. (2004). Inquiry in science education: International perspectives. *Science Education, 88*(3), 397–419.

American Association for the Advancement of Science. (1993). *Science for all Americans: Project 2061*. New York: Oxford University Press.

American Association for the Advancement of Science. (1998). *Blueprints for reform: Science, mathematics and technology education*. New York: Oxford University Press.

Azevedo, R., & Hadwin, A. F. (2005). Scaffolding self-regulated learning and metacognition: Implications for the design of computer-based scaffolds. *Instructional Science, 33*, 367–379.

Bruck, L. B., Bretz, S. L., & Towns, M. A. (2008). Research and teaching: Characterizing the level of inquiry in an undergraduate laboratory. *Journal of College Science Teaching, 9*, 52–58.

Chinn, C. A., & Hmelo-Silver, C. E. (2002). Authentic inquiry: Introduction to the special section. *Science Education, 86*(2), 171–174.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating in inquiry tasks. *Science Education, 86*(2), 175–218.

Clark, S. A., & Jackson, D. F. (1998). *Laboratory technology and student motivation in a conceptual physics classroom: A year-long case study*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Cox, M. J., & Webb, M. E. (2004). *ICT and pedagogy: A review of the research literature*. Coventry/London: British Educational Communications and Technology Agency/Department for Education and Skills. http://partners.becta.org.uk/upload-dir/downloads/page_documents/research/ict_pedagogy_summary.pdf. Accessed 16 Apr 2009.

Duschl, R. A. (1990). *Restructuring science education: The importance of theories and their development*. New York: Teachers College Press.

Edelson, D. C. (1998). Realising authentic science learning through the adaptation of science practice. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 317–331). London: Kluwer Academic Publishers.

Edelson, D. C. (2001). Learning-for-use: A framework for the design of technology-supported inquiry activities. *Journal of Research in Science Teaching, 38*(3), 355–385.

Friedler, Y., Nachmias, R., & Songer, N. (1989). Teaching scientific reasoning skills: A case study of a microcomputer-based curriculum. *School Science and Mathematics, 89*(1), 272–284.

Friedler, Y., Nachmias, R., & Linn, M. C. (1990). Learning scientific reasoning skills in microcomputer-based laboratories. *Journal of Research in Science Teaching, 27*(2), 173–192.

Gengarelly, L. M., & Abrams, E. D. (2009). Closing the gap: Inquiry in research and the secondary science classroom. *Journal of Science Education and Technology, 18*(1), 74–84.

Hannafin, R. D., & Scott, B. N. (2001). Teaching and learning with dynamic geometry programs in student-centered learning environments: A mixed method inquiry. *Computers in the Schools, 17*, 121–141.

Hill, J. R., & Hannafin, M. J. (2001). Teaching and learning in digital environments: The resurgence of resource based learning. *Educational Technology Research and Development, 49*(3), 37–52.

Hodson, D. (1988). Toward a philosophically more valid science curriculum. *Science Education, 72*(1), 19–40.

Kim, M. C., Hannafin, M. J., & Bryan, L. A. (2007). Technology-enhanced inquiry tools in science education: An emerging pedagogical framework for classroom practice. *Science Education, 91*(6), 1010–1030.

Krusberg, Z. A. C. (2007). Emerging technologies in physics education. *Journal of Science Education and Technology, 16*(5), 401–411.

Lim, B. R. (2004). Challenges and issues in designing inquiry on the web. *British Journal of Educational Technology, 35*(5), 627–643.

Maor, D., & Fraser, B. J. (1996). The development and use of a classroom instrument in the evaluation of inquiry-based computer-assisted learning. *International Journal of Science Education, 18*, 401–421.

McRobbie, C. M., & Thomas, G. P. (2000). Epistemological and contextual issues in the use of microcomputer-based laboratories in a Year 11 Chemistry classroom. *Journal of Computers in Mathematics and Science Teaching, 19*(2), 137–160.

Mistler-Jackson, M., & Songer, N. B. (2000). Student motivation and internet technology: Are students empowered to learn science? *Journal of Research in Science Teaching, 37*(5), 459–479.

Nakhleh, M. B., & Krajcik, J. S. (1994). The effect of level of information as presented by different technologies on students' understanding of acid, base and pH concepts. *Journal of Research in Science Teaching, 31*(10), 1077–1096.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *National science education standards*. Washington, DC: National Academy Press.

Olson, S., & Loucks-Horsley, S. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academy Press.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts & P. R. Pintrich (Eds.), *Handbook of self-regulation* (pp. 13–39). San Diego: Academic.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., et al. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*(3), 337–386.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences, 13*(3), 273–304.

Schwartz, R. S., & Crawford, B. A. (2006). Authentic scientific inquiry as context for teaching nature of science: Identifying critical elements for success. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education* (pp. 331–355). Dordrecht: Springer.

Settlage, J. (1995). Children's conceptions of light in the context of a technology-based curriculum. *Science Education, 79*(5), 535–553.

Sokoloff, D. R., & Thornton, R. K. (1997). Using interactive lecture demonstrations to create an active learning environment. *The Physics Teacher, 35*, 340–346.

Songer, N. B. (1998). Can technology bring students closer to science? In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 333–347). Dordrecht: Kluwer.

Thornton, R. K., & Sokoloff, D. R. (1990). Learning motion concepts using real-time microcomputer-based laboratory tools. *American Journal of Physics, 58*, 858–866.

Tytler, R. (1992). Independent research projects in school science: Case studies of autonomous behavior. *International Journal of Science Education, 14*, 393–411.

van der Valk, T., & de Jong, O. (2009). Scaffolding science teachers in open-inquiry teaching. *International Journal of Science Education, 31*(6), 829–850.

Waight, N., & Abd-El-Khalick, F. (2007). The impact of technology on the enactment of "inquiry" in a technology enthusiast's sixth grade science classroom. *Journal of Research in Science Teaching, 44*(1), 154–182.

Winters, F. I., Greene, J. A., & Costich, C. M. (2008). Self-regulation of learning within computer-based learning environments: A critical analysis. *Educational Psychology Review, 20*, 429–444.

Wong, S. L., Hodson, D., Kwan, J., & Yung, B. H. W. (2008). Turning crisis into opportunity: Enhancing student-teachers' understanding of nature of science and scientific inquiry through a case study of the scientific research in severe acute respiratory syndrome. *International Journal of Science Education, 30*(11), 1417–1439.

Zimmerman, B. J., & Tsikalas, K. E. (2005). Can computer-based learning environments (CBLEs) be used as self-regulatory tools to enhance learning? *Educational Psychologist, 40*(4), 267–271.

Zion, M. (2006). On line forums as a "rescue net" in an open inquiry process. *International Journal of Science and Mathematics Education, 6*(2), 351–375.

Zion, M., & Sadeh, I. (2007). Curiosity and open inquiry learning. *Journal of Biological Education, 41*(4), 162–168.

Zion, M., & Slezak, M. (2005). It takes two to tango: In dynamic inquiry, the self-directed student acts in association with the facilitating teacher. *Teaching and Teacher Education, 21*, 875–894.

Zion, M., Shapira, D., Slezak, M., Link, E., Bashan, N., Brumer, M., et al. (2004). Biomind – A new biology curriculum that enables authentic inquiry learning. *Journal of Biological Education, 38*(2), 59–67.

Chapter 8
Developing a Peer-Coaching Model for Enhancing the Pedagogical Content Knowledge of Preservice Science Teachers

Syh-Jong Jang

8.1 Introduction

Current teacher education courses for preservice teachers in Taiwan can be classified into two main categories: courses on subject-matter knowledge and those on education professional knowledge (Jang 2007, 2008a, b). However, several studies have pointed out that many preservice teachers who study science teaching knowledge, theories, methods, and skills actually have difficulties coping with the practical teaching situation (Jang 2007; Hashweh 2005). It has also been reported that the success of science teaching depends not only on the teachers' subject-matter knowledge but also on their personal understanding of students' prior knowledge and learning difficulties (Grossman 1990; Lederman et al. 1994). In addition, other factors of success include their own teaching methods and strategies, curriculum knowledge, educational situation, goal, and value (Shulman 1987). In particular, the preservice teachers' pedagogical content knowledge (PCK) is one of the main issues in current teacher education (De Jong et al. 2005; Grossman 1990; Shulman 1986, 1987).

Shulman's notion of PCK has attracted much attention and has been interpreted in different ways (Geddis et al. 1993; Gess-Newsome and Lederman 1999; Grossman 1990). The foundation of science PCK is thought to be an amalgam of a teacher's pedagogy and understanding of science content such that it influences their teaching in ways that will best engender students' science learning for understanding. Initially, preservice teachers separate subject-matter knowledge from general pedagogical knowledge. These types of knowledge are, however, being integrated as a result of teaching experiences. By getting acquainted with the specific concepts and

---

S.-J. Jang (✉)
Graduate School of Education, Chung-Yuan Christian University,
200 Chung-Pei Road, Chung Li, Taiwan
e-mail: jang@cycu.edu.tw

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_8,

ways, preservice teachers may start to restructure their subject-matter knowledge into a form that enables more productive communication with their students (Lederman et al. 1994). According to Lederman et al. (1994), the development of PCK among preservice science teachers is promoted by the constant use of subject-matter knowledge in different teaching situations. Many scholars suggest that PCK is developed through an integrative process rooted in classroom practice, and that PCK guides the teachers' actions when dealing with a specific subject matter in the classroom. In addition to field-based experience, preservice teachers may benefit from studying the students' preconceptions with respect to a specific topic during teacher education courses and then comparing and discussing these preconceptions in relation to their own concepts (Geddis 1993). Such activities may stimulate preservice teachers to transform their subject-matter knowledge and topic-specific teaching strategies.

Related to the result of teaching experiences, meaningful collaboration is at the center of professional development (Jang 2006; Lieberman 1995; Little 1993). Peer coaching is a collaborative and confidential process in which two or more professional colleagues work together to provide in-class assistance, reflect on current practices, build new skills and knowledge, share ideas, and solve problems (Joyce and Showers 1995; McAllister and Neubert 1995; Slater and Simmons 2001). Joyce and Showers (1995) suggested that teachers learn from each other in the process of planning instruction, developing the materials to support it, watching each other work, and thinking together about the impact of their behavior on the learning process of their students. A major benefit of peer coaching is that it can provide a valuable tool for collaboration, evaluate teaching effectiveness, and improve teaching quality (Marshall 2005). Some studies indicate that peer coaching is viewed as a means of active learning where teachers construct their own knowledge (McAllister and Neubert 1995) and improve their ability to plan and organize the classroom activities (Hasbrouck 1997). Previous investigations have examined the practicality of peer coaching for promoting changes in teachers' pedagogical practices and expertise (Kohler and Ezell 1999; Pugach and Johnson 1995). Peer coaching can increase reflective practice, aid implementation of teaching models and instructional strategies, and enhance classroom management and the development of pedagogical content knowledge (Jenkins and Veal 2002; McAllister and Neubert 1995).

Many related studies have indicated that instructional models related to teachers' reflection and teaching experience are important for PCK development (De Jong et al. 2005; Loughran et al. 2004; Van Dijk and Kattmann 2007; Van Driel et al. 2002). However, there have been few studies integrating peer coaching into preservice teachers' PCK. This current study revises the peer-coaching model proposed by Joyce and Showers (1995) into the PCK-COPR model (PCK Comprehension, Observation, Practice, and Reflection). The purpose of this study was to examine the content of preservice teachers' initial PCK of learning difficulties, instructional strategies, and the effect of PCK using the PCK-COPR model. In this study, the concepts of "density and buoyancy" were chosen to explore the effects of the intended design since students have particular difficulty understanding abstract, invisible, process, and hierarchical level attributes (Brown 1993). The specific research questions that guided this study were as follows:

1. What is the content of preservice teachers' initial PCK of learning difficulties concerning the topics of "density and buoyancy?"
2. What is the content of preservice teachers' initial PCK of instructional strategies they consider useful?
3. What is the effect of preservice teachers' PCK using the PCK-COPR model?

8.2 Theoretical Framework

8.2.1 Preservice Science Teachers' PCK

The impact of constructivist epistemology seems to be important in PCK. Since constructivism emphasizes the role of previous experience in knowledge construction processes, it is not surprising that teachers' knowledge is studied in relation to their practice from the constructivist point of view. Shulman (1987) regarded PCK as the knowledge base for teaching. This knowledge base comprises seven categories, three of which are content related (content knowledge, PCK, and curriculum knowledge). The other four categories refer to general pedagogy, learners and their characteristics, educational contexts, and educational purposes. The crucial factor in PCK development is, obviously, teaching experience (De Jong et al. 2005; Gess-Newsome and Lederman 1993; Van Dijk and Kattmann 2007; Van Driel et al. 2002). PCK implies a transformation of subject-matter knowledge, so that it can be used effectively and flexibly in the communication process between teachers and learners during classroom practice. Thus, teachers may derive PCK from their own teaching practice as well as from schooling activities. Teaching practice was investigated as a function of familiarity with a specific domain. These studies lead to similar results, indicating that preservice teachers, when teaching unfamiliar topics, have little knowledge of potential student problems and specific preconceptions and have difficulties selecting appropriate representations of subject matter. Moreover, when teaching unfamiliar topics, teachers reveal more of their own misconceptions (Hashweh 1987), they talk longer, and, more often, the questions they pose tend to be low cognitive level (Carlsen 1993). These results are interpreted in terms of PCK rather than subject-matter knowledge (Sanders et al. 1993). Pedagogical knowledge provides a framework for teaching that can be "filled in by content knowledge and pedagogical content knowledge … when teachers taught within and outside their science area" (Sanders et al. 1993, p. 733). Geddis (1993) studied the transformation of preservice science teachers' subject-matter knowledge into "teachable content knowledge." PCK has been described as the transformation of several types of knowledge for teaching (Magnusson et al. 1999).

Preservice or novice science teachers usually express little PCK (Lederman et al. 1994). Lederman et al. (1994) investigated the self-reported changes in preservice science teachers' conceptions of subject matter and pedagogy. Although distinct changes in both knowledge domains seem to take place mainly as a result of teaching experiences, it does not seem that preservice teachers integrate these domains. Again, they attributed this to a lack of teaching experience, suggesting that "with the benefit of experience and continual use of one's subject matter structure for purposes of teaching, the division between pedagogical knowledge and subject matter knowledge may become blurred" (Lederman et al. 1994, p. 143). Thus, the development of PCK may be postponed until teachers reach this stage. Most importantly, however, the observation that the translation of these subject-matter structures into classroom practice appeared to be complicated by classroom complexity. Lederman et al. (1994) suggested that until a preservice teacher has gained experience and mastered basic classroom skills, it might be unrealistic to expect a readily accessible and useful translation of subject-matter knowledge into classroom practice.

8.2.2 Peer Coaching

Peer coaching provides a community of practice to be defined as a group of individuals who share such commonalities as interests, knowledge, resources, experiences, perspectives, behaviors, language, and practices (Barab and Duffy 2000; Lave and Wenger 1991). Norms of isolation can be overcome by creating professional school communities with shared values, collaborative action, and reflective dialogue (Louis and Marks 1998; Ross and Bruce 2007). A structured approach for doing this is to use peer-coaching pairs of teachers of equal experience and competence who can observe each other teach, negotiate improvement goals, devise strategies to implement the goals, observe the improved teaching, and provide each other with feedback. Peer coaching has positive effects when the appropriate climate, involving mutual trust, genuine voluntarism, encouragement of reflective thinking, and principal support, is developed. Successful peer coaching depends on developing a climate of trust and mutual respect. When trust exists, the team members will stay focused on their goals, communicate more effectively, and compensate for each other's shortcomings, thereby improving in the overall quality of outcomes (Davies 1995). The coaching relationship also results in the possibility of mutual reflection, checking of perceptions, sharing of frustrations and successes, and the informal thinking through mutual problems (Joyce and Weil 1996). This involves identifying and honoring different perspectives, strengths, and weaknesses of all team partners (Joyce and Showers 1995; Koballa 1992). Therefore, peer coaching must focus on improving rather than rating the quality of teaching, and it must not be used for the evaluation or judgment of teachers' performance (Showers and Joyce 1996; Skinner and Welch 1996; Valencia and Killion 1998).

Three characteristics have become common to the variety of peer-coaching approaches that have been developed over the years. First, peer coaching is a formative process that facilitates introspection and self-awareness prior to, during, and after teaching. Teachers work collaboratively and systematically to talk about their teaching, outlining intended outcomes prior to teaching, then reflecting upon the actual teaching experience afterward. They meet repeatedly and actively engage in conversations aimed at building upon each experience in a nonthreatening dialogue (Goker 2006). Second, peer-coaching models draw on elements of the clinical supervision cycle. Joyce and Showers (1982) have developed the most widely known peer-coaching model which consists of four elements: (1) study of the theoretical basis or rationale of the teaching method, (2) observation of demonstrations by persons who are experts in the teaching method, (3) practice and feedback in relatively protected conditions, and (4) mutual coaching to help incorporate the new method into an everyday teaching style. In their early work, peer coaching includes a cycle of objective classroom observation, followed by accurate feedback on the use of the new teaching skills. In their more recent work, Joyce and Showers (1995) expanded their view of peer coaching, emphasizing learning through collaborative planning, development, and observation of instruction. They stress the importance of a nonhierarchical relationship between peers working and learning collaboratively to improve their teaching. Third, peer-coaching models aim to improve classroom practice. In general, teachers gain greater awareness of their actions in the classroom and the effect their teaching has on their students. Teachers develop their own criteria for assessment to improve their practice. Although formative assessment is not directly associated with institutional decisions, the intention is to create positive change that ultimately results in improved teaching practices (Goker 2006; Thijs and Van den Berg 2002).

8.2.3 *Developing a Peer-Coaching Model for PCK*

Shulman (1987) proposed that PCK development might pass through the processes of comprehension, transformation, instruction, evaluation, reflection, and new comprehension. In this study, peer coaching can be described as a collegial approach to the analysis of teaching aimed at integrating new skills and strategies in classroom practice. This study revised the instructional model proposed by Joyce and Showers (1995) into the PCK-COPR model (PCK Comprehension, Observation, Practice, and Reflection) as shown in Fig. 8.1. This model is comprised of four main activities: (1) comprehension of PCK, (2) observation of instruction, (3) practice of PCK, and (4) reflection of PCK. First, the peer-coaching model starts at the study of the theoretical basis or rationale of the specific content teaching method. The understanding includes study on the topics of textbook and PCK articles. The preservice teachers discuss PCK concepts and theories in teams, and they describe his/her understanding of the subject-matter knowledge of specific subject content unit. The analyses and discussions on these PCK research articles also contribute to the science teacher's PCK of useful instructional strategies for overcoming secondary students' learning difficulties (Van Driel et al. 2002). Second, in order to integrate PCK theories and

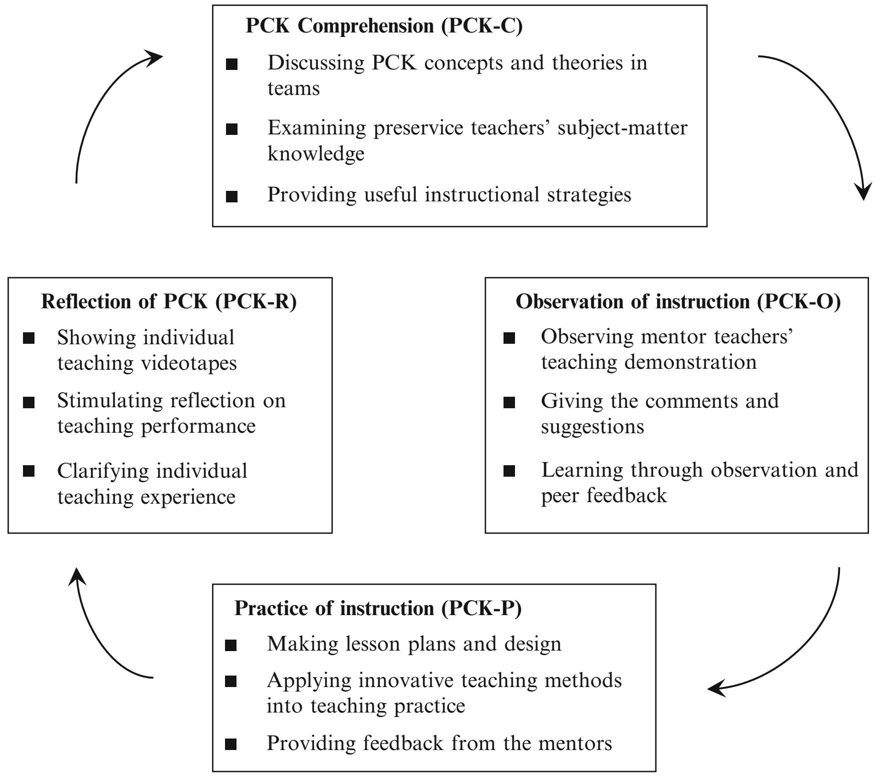


Fig. 8.1 The PCK-COPR model

practice, the second main activity is to observe experienced mentor teachers' teaching demonstration. The preservice teachers should observe the teaching and notify their skills according to the learned PCK theories and strategies. After watching the demonstration, preservice teachers take turns to give their comments and suggestions. Then preservice teachers could learn through their observation and peer feedback. Third, preservice teachers learn to make lesson plans and design, and apply innovative teaching methods and strategies into teaching practice. After the practices, the mentors would provide and comment on the pros and cons of their teaching. Finally, each preservice teacher should show the videotapes of his/her teaching to share his/her teaching experience with others. This teaching practice can stimulate teachers' self-reflection. To reflect is to think about where you have been and/or what has happened in order to clarify your teaching experience (Vidmar 2006).

Jenkins et al. (2005) suggested peer coaching as a means of developing PCK because of its real-life context, in which teaching and learning can occur together. Science teachers' PCK was formed to be deeply personal, highly contextualized, and influenced by teaching interaction and experience (De Jong et al. 2005; Van Dijk and Kattmann 2007; Van Driel et al. 2001). Mulholland and Wallace (2005) suggested that science teachers' pedagogical content knowledge requires the longitudinal development of experience as they transition from novices to experienced teachers. Within the framework of peer-coaching practice, such collaborative discussions allow individuals to develop their own perspectives and to model strengths for others. Bowman and McCormick (2000) suggest that through social interaction, active learning evolves and each participant interprets, transforms, and internalizes new knowledge. Pierce and Hunsaker (1996) state that peer coaching not only increases collegiality but also enhances each teacher's understanding of the concepts and strategies of teaching and sustains the movement toward restructuring the traditional evaluation efforts by strengthening the ownership of change.

8.3 Research Methodology

8.3.1 Participants and Context

The participants included a single instructor and a total of 12 preservice teachers. The instructor, who was the primary researcher, specializes in science teaching methods and strategies. The preservice teachers were selected from a 2-year teacher education program from a university science college, and they were all interested in becoming a science teacher in secondary schools. The context of this study was a science teacher education course, "Teaching Practice of Secondary Science," designed so preservice teachers could gain teaching experience, pedagogical knowledge, and teaching methods and techniques by attending the teaching practice. In this study, the core course lasted 16 weeks, throughout the whole semester, and the teaching practice was designed as a three-stage process. The first stage involved a 6-week practice at the university, where the major activities included PCK understanding and observation of the mentor teachers' teaching. The second stage involved a 7-week practice teaching in a secondary school, for which the preservice teachers made their own teaching designs and practiced teaching to the secondary students. The topics taught included "density and buoyancy." At the same time, they had their teaching performance videotaped for evaluation. The final stage involved a 3-week review and evaluation of performance, when preservice teachers completed the school teaching practice and returned to the university. Every preservice teacher was required to present what they learned during the teaching practice and show his/her teaching videos for further evaluation.

8.3.2 Procedures and Research Instruments

The four activities of the PCK-COPR model (as Fig. 8.1) were integrated into the overall course in three stages as discussed below.

8.3.2.1 Stage One: PCK Comprehension and Observation

Comprising the first 6 weeks, this stage included two main activities: understanding the content of PCK and observing the in-service mentor teachers' teaching. In the first activity, the instructor, using PowerPoint, explained the meaning and concepts of PCK in seven categories, especially students' required knowledge and creative teaching strategies. Moreover, the preservice teachers were divided into collaborative teams, each of which had 3–4 people, so the preservice teachers could study the content of PCK in teams. Every preservice teacher would describe his/her understanding of the subject-matter knowledge of specific subject content unit on density and buoyancy in writing assignment. During the first stage, they were asked to answer the following question:

> Assignment 1: What difficulties in learning the concepts of "density or buoyancy" do you remember from your earlier experiences as a secondary student, as a university student, or from your previous teaching practice?

The preservice teachers wrote down their recollections individually, which were then discussed by all. After the discussion and examination in a group, the preservice teachers would note down the knowledge of students' understanding and preconceptions of these topics in their reflective journals.

In order to integrate PCK theories and practice, the second main activity was to have two experienced mentor science teachers demonstrate their teaching with respect to the unit—"density" in the university. For example, one mentor used a multimedia videotape to illustrate the different objects of density and compare their density in computer flash experiments. The preservice teachers should observe the teaching and their skills. Furthermore, in addition to their written assignment, the preservice teachers also discussed the integration of mentor teachers' teaching strategies or methods according to their own acquired PCK. Before peer discussions on these sections, the preservice teachers were asked to write down their individual responses to the following assignment:

> Assignment 2: (a) What teaching skills or strategies for understanding these topics did you observe? (b) Give some examples of instructional strategies that you may use to promote students' understanding of these topics.

Again, all written responses were collected, and the subsequent group discussion was recorded on their reflective journals.

8.3.2.2 Stage Two: PCK Practice

The third activity was carried out from week 7 to week 13. The preservice teachers learned to make lesson plans, and they applied innovative teaching methods and strategies into their teaching practice in the secondary school. Each preservice teacher was assigned to an experienced guidance mentor who served as a coach for consultation on problems encountered. The goal of this stage was to have preservice teachers acquire teaching experience and to understand secondary school students' prior knowledge and learning difficulties. Specifically, in this stage, each preservice teacher demonstrated his/her teaching to the secondary classroom. Each preservice teacher might integrate the previously learned PCK strategy and skills from observing the mentor teachers' teaching. Thus, the guidance mentor observed his/her performance and acted as backup to assist and respond promptly to the preservice teacher if necessary. For example, a preservice teacher used a buoyancy meter to demonstrate the buoyancy phenomenon of water and used a computer to assist in this demonstration. After the trial teaching, the guidance mentor would criticize and analyze the observation about teaching strategies and related teaching activities used by the preservice teacher. The preservice teachers also had their teaching performance videotaped. In addition, they wrote down their own thinking and raised questions in their reflective journals.

8.3.2.3 Stage Three: Reflection and Modification

The fourth activity on reflection and modification lasted from week 14 to week 16. After completing the teaching practice, preservice teachers returned to the university campus to continue with the course. They showed the video recordings of their teaching, shared with others their teaching experience, and noted their reflection in their journals. The purpose of this activity was to evaluate preservice teacher's teaching performance. Preservice teachers of each group would take turns to reflect on their own practice, followed by comments from other peers. Finally, the instructor would give appropriate feedback and comment on their demonstration and practice. In this stage, the model aimed at making the preservice teachers aware of the PCK they had developed after, and as a result of, teaching. They were asked to write an individual reflective assignment about students' learning difficulties and about the instructional model, using the following guidelines:

> Assignment 3: (a) What difficulties of students did you identify? (b) What effects on this course did you gain concerning the PCK-COPR model?

All written assignments were collected and, again, the concluding group discussion was recorded on their journals. Furthermore, the reflective stage helped them self-examine their current lesson plan design and teaching practice in order to modify future teaching practice.

8.3.3 Data Collection and Analysis

To monitor the development of PCK during this module, data were collected at specific moments that were closely associated with the design of PCK-COPR. The data collected consisted of (a) the written assignments of each individual preservice teacher to the questions and assignments included in the four parts of the model, (b) the reflective journal written by the preservice teachers through the overall process of the model and this course, and (c) the video recordings of lessons about the chosen topics that took place during the teaching practice. These recordings were transcribed verbatim.

The inductive data analysis employed in this study utilized a qualitative framework that allowed the researcher to build patterns of meaning from the data (McMillan and Schumacher 2001). Four phases, as described by McMillan and Schumacher, were employed for the analysis of the transcripts: (1) continual discovery throughout the research in order to tentatively identify patterns, (2) categorizing and ordering data, (3) refining patterns by determining the trustworthiness of the data, and (4) synthesizing themes. Accordingly, the researcher assigned the changes found from individual respondents to these categories, resulting in a numerical overview of the results. A constant comparative method was utilized to compare the written assignment data and other data (reflective journals and videotapes) with the categories generated (Strauss 1987). The data were first collected, coded, compared, and then organized into different categories. Then the data were interpreted according to the categories.

8.4 Results and Discussion

Throughout this section, this study refers to preservice teachers using names that are different from their real names. Female names, however, refer to female teachers and male names to male teachers. According to the purpose and research questions, this study examined the content of preservice teachers' initial PCK of learning difficulties, instructional strategies, and the effect of the PCK-COPR model. Therefore, the results were divided into the following three categories.

8.4.1 Preservice Teachers Were Clearly Aware of Students' Prior Conceptions of the Subject Matter and Their Learning Difficulties

In the first writing assignment, four of the preservice teachers thought that they might have some misconceptions about the density and buoyancy remaining from their earlier experiences as schoolboys or schoolgirls and as university students, or from their previous teaching practice (Assignment 1). They seemed to have sufficient basic knowledge related to density and buoyancy, however, although they might not understand the abstract nature of the conceptions and the theoretical formula. Four of the preservice teachers stated:

> Hard objects have higher density, and objects with higher density have larger volume and greater weight. (Mary, written assignment)
>
> Lighter objects will float, and heavier objects will sink. Objects floating on the surface of water have more buoyancy than those sinking in the water. (John, written assignment)

> Since density, mass and volume are abstract conceptions, which are complicated to comprehend, students might confuse the mass and the weight in the formulation of density conceptions. (Peter, written assignment)
>
> Most of the students have basic conceptions about buoyancy; for example that a wood block floats on the water and a piece of iron sinks. However, this does not mean that students actually understand the buoyancy concept formula. (Amy, written assignment)

However, in the third written assignment "what difficulties of students did you identify?" Preservice teachers considered themselves clearly aware of students' prior conceptions of the subject matter and their learning difficulties. Mary (preservice teacher) understood students' levels of comprehension for the concept of density after teaching practice. John used some examples adopted from real-life experience to motivate students to learn. Peter thought that they were equipped with science content knowledge. However, this science content knowledge seemed very objective to them before the teaching practice experience. In addition, Amy acquired the ability to integrate theoretical concepts and knowledge into their teaching practices.

> After the teaching practice, it was easier for me to understand students' levels of comprehension for the concept of density. (Mary, reflective journal)
>
> I use some concrete objects as the material for theoretical implications into my teaching content. This is intended to reduce confusion due to abstract conceptions, and also to stimulate students' interest in learning. (John, written assignment)
>
> Before the course, my knowledge of "density" was objective and formal, as simply the mass per volume for an object. After the teaching practice, I understood the definition of density and how it is calculated, as well as the density characteristics of an object or the density difference between different objects. (Peter, reflective journal)
>
> I found that some students probably understand the concept of buoyancy, but it is still difficult for them to apply it correctly when solving problems. They did not know how to use a formula to express the physical significance to solve problems. In my opinion, there is significant difference between students' acquired knowledge in the science course and their problem-solving capability. (Amy, written assignment)

8.4.2 Preservice Teachers Learned to Implement Multiple Teaching Methods for Integrating the Subject-Matter Knowledge

After focusing on their expected learning difficulties, preservice teachers wrote down and discussed instructional strategies that they considered potentially useful to enhance students' understanding (Assignment 2). Six of the preservice teachers noted that this study enabled them to improve successfully their pedagogical knowledge. The main difficulty they encountered was how to present the science formula and content knowledge to students in an efficient way. However, from the PCK training, preservice teachers learned how to implement multiple teaching methods and strategies of integrating subject-matter knowledge into real-life examples, which helped them better explain the content knowledge. Preservice teachers thought that they had developed some strategies after they read and discussed the related PCK papers. They also might explain important concepts by designing some activities to give students the chance to practice and enrich their empirical experience. Peer coaching provided the opportunities for collaborative teachers to develop their skills in applying technology to design lessons as well as to improve their teaching skills. Meanwhile, preservice teachers were the reflective coaches for each other because they could faithfully reflect their observations on teaching practice. Six of the preservice teachers stated:

> To design a teaching activity for explaining the abstract buoyancy concept formula to students was not easy. Thus, I used materials from everyday life to guide the students. For example, I used clay as a demonstration material, broke it into lumps of different sizes, and put them into water so students could observe whether they floated or sank. (Caleb, written assignment)
>
> For me, being aware of students' learning conditions and offering activities to students are important points for successfully teaching abstract density concepts. (Dick, written assignment)
>
> The research papers helped me a lot in developing my instructional strategy. After I explain the important concepts, I will provide some activities for the students to check their understanding. (Bee, reflective journal)
>
> I think that using the computer in teaching not only could help explore scientific concepts but is an entertaining effect, thus enhancing the students' motivation to learn. I learned much computer skill from peer coaching in this study. (Ann, videotape)
>
> Through peer coaching, we could work collaboratively to elaborate each other's specialties and develop our skills in employing technology to design more interesting and lively teaching contents. I think it will help my teaching. (Jim, written assignment)
>
> Peer coaching requires preservice teachers to be open-minded to both positive and negative feedbacks from peers. Positive feedback could enhance their teaching skills while negative feedback could modify their teaching. (Paul, reflective journal)

8.4.3 The Teaching Model Offered Preservice Teachers' Observation and Practical Opportunities to Promote Their PCK

After focusing on instructional strategies, preservice teachers wrote down the effect of the PCK-COPR model that they considered potentially useful to enhance their PCK (Assignment 3). The initial process of teaching observation and peer interaction in the study could help an individual who did not have any teaching experience. Further, it helped preservice teachers learn some practical teaching strategies and organize their personal thinking. Preservice teacher also learned some multimedia technology by observing the mentor teacher's teaching demonstration in class. Three of the preservice teachers stated:

> Observing an experienced teacher can help oneself integrate theoretical knowledge with practice. The most important is his/her self-reflection, which may differ from others and from books. (Paul, written assignment)
>
> Previously, I offered only one exercise for students to practice their learning after explaining three concepts. After observing a mentor teacher's teaching strategies, I found that offering

> a related exercise after explaining each concept is more effective teaching method. (Caleb, reflective journal)
>
> I created a multimedia VCD to illustrate the different objects of density and their applications. This idea was inspired through observing a mentor teacher's instruction. (Jim, videotape)

On the other hand, the teaching model (PCK-COPR) offered preservice teachers a teaching practice opportunity to promote their PCK, and so it was possible for preservice teachers to connect their professional knowledge of the subject matter with their teaching methods. In addition, preservice teachers learned how to interpret the teaching units in a way that was more comprehensive than the traditional teaching method. Two of the preservice teachers stated:

> The model gave me lots of practical experience and helped me integrate content knowledge and teaching skills in actual classroom practice. It helped me clarify the areas of strength and weakness in my teaching. (Sue, written assignment)
>
> The model helped me select a proper teaching method to interpret the subject matter for the unit of density in a more comprehensible way, and thereby revised my previous teaching method. (Robert, reflective journal)

8.5 Conclusion and Implications

This study first examines the content of preservice teachers' initial PCK of learning difficulties. Initially, preservice teachers thought that they might have some misconceptions about the density and buoyancy from their earlier experiences; however, the preservice teachers considered themselves clearly aware of students' prior conceptions of "density and buoyancy" and their learning difficulties after teaching practice (Mary, John, Peter, and Amy). By getting acquainted with students' specific conceptions and ways of learning, preservice teachers might use some examples adopted from real-life and practical experience to motivate students to learn. This would restructure their subject-matter knowledge into more easily understood form that enables productive communication with their students (Lederman et al. 1994). This study also provides empirical evidence showing that the teaching model did have some impact on preservice teachers' PCK. Some studies have shown that preservice teachers' PCK would improve with increasing teaching experience and practice (De Jong et al. 2005; Van Driel et al. 2002). According to the results of this study, the PCK-COPR model was found to enhance the integration of science knowledge of theory and teaching practice. Since the science concepts and theories learned by the traditional teaching method were usually considered objective and abstract, the preservice teachers found it easier for them to combine the theory with practice and further organize their subject-matter knowledge through the teaching model. It was possible for preservice teachers to connect their professional subject-matter knowledge with their teaching methods (Lederman et al. 1994). Preservice teachers developed their pedagogical content knowledge, which has been described as the transformation of several types of knowledge for teaching (Magnusson et al. 1999).

According to Geddis (1993), the transformation turned preservice science teachers' subject-matter knowledge into teachable content knowledge.

Moreover, preservice teachers' knowledge of representations and teaching strategies benefited from and developed in the actual teaching experience. This strong impact of teaching experiences is consistent with the findings of other scholars (De Jong et al. 2005; Grossman 1990; Lederman et al. 1994). It was found that the present PCK-COPR model could help preservice teachers develop multiple teaching methods and strategies for integrating the subject-matter knowledge into real-life examples of the science lessons. Some of the preservice teachers admitted that this study enabled them to improve their pedagogical knowledge (Caleb, Dick, Bee, Ann, Jim, and Paul). On the other hand, in the study of De Jong et al. (2005), the preservice teachers were not offered research articles about secondary students' learning difficulties or relevant teaching approaches to prepare their lessons. Instead, they were stimulated to explicate their already existing PCK and to expand this PCK by analyzing and discussing secondary school textbook sections. In this study, analyses and discussions on these PCK research articles also contributed to the preservice teachers' PCK of useful instructional strategies for overcoming secondary students' learning difficulties (Van Driel et al. 2002). In general, reading and discussing the paper triggered the development of pedagogical knowledge for at least some of the participating preservice teachers. Thus, preservice teachers might be better able to develop effective strategies for explaining the important concepts by designing some exercises for students to experiment with the concepts they had acquired.

Another finding was that observing the mentor teacher's teaching demonstration in the study could help preservice teachers to learn some practical teaching strategies and organize their personal reflection and thinking (Paul, Caleb, and Jim). The teaching model (PCK-COPR) also provided preservice teachers a teaching practice opportunity to promote their PCK (Sue and Robert). Preservice teachers considered these perspectives potentially useful to enhance their PCK. These findings echoed that some preservice teachers also learned how to use technology and to illustrate teaching content using the computer as taught by their peer coach (Ann and Jim). The preservice teachers in this study were trained to play two different kinds of roles: collaborative coaching and reflective coaching in the activities. As collaborative coaches, preservice teachers were asked to observe and analyze the teaching practice; they learned from each other on how to design more interesting and lively teaching contents and refine teaching skills through immediate feedback (Bowman and McCormick 2000). Preservice teachers were also the most appropriate reflective coaches for each other (Vidmar 2006). In this regard, when the preservice teachers provided feedbacks to each other, they not only gave suggestive but also positive feedbacks in order to facilitate peer's teaching skills and strategies. They should be more open to critical suggestions for PCK improvement and changes offered by the supportive peers. Therefore, the experimental PCK-COPR model including peer coaching has its advantages in these respects.

Comparing the outcomes of the present study with the previously described peer-coaching model for developing PCK, drawn from the research literature, the researcher can conclude that the design of the PCK-COPR model helped develop the PCK of the participating preservice teachers. That is, it was useful to start the model with activities focusing on explaining preservice teachers' initial knowledge of secondary students' conceptions and learning difficulties. Then, these notions could be expanded through analyzing and discussing fragments from PCK comprehension activities. The activity also appeared to stimulate their thinking about potentially useful instructional strategies. Next, the initial process of teaching observation in the study helped individuals who did not have any teaching experience. It helped preservice teachers learn some practical teaching strategies and organize their personal thinking to verify the theories they had learned from textbooks. Thus, it was important that preservice teachers were provided with authentic opportunities to experiment with teaching approaches. In this context, some of them focused on the design of their instructional approach, whereas others reflected that they had concentrated on how to integrate technologies with teaching. The mentors' approach and involvement confirmed their potentially strong impact on the development of preservice teachers' PCK (Van Driel et al. 2002). Finally, writing a reflective assignment, reflective journal, and discussion of the video recordings with each other was useful in helping the preservice teachers reflect and further develop their PCK about students' learning difficulties and instructional strategies. The data also show that the learning outcomes of this model, in terms of PCK development, were different for different preservice teachers and mostly limited to the specific topics (density and buoyancy) that were focused on. The design of this PCK-COPR model, whether it is suitable for other topics of science, needs a follow-up study. Again, the innovative PCK-COPR model provides a way to develop science preservice teachers' PCK and also serves as useful reference for other pedagogical goals.

References

Barab, S. A., & Duffy, T. M. (2000). From practice fields to communities of practice. In D. H. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 25–55). Mahwah: Lawrence Erlbaum Associates.

Bowman, C., & McCormick, S. (2000). Comparison of peer coaching versus traditional supervision effects. *The Journal of Educational Research, 93*(4), 256–264.

Brown, D. E. (1993). Refocusing core intuitions: A concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching, 30*(10), 1273–1290.

Carlsen, W. S. (1993). Teacher knowledge and discourse control: Quantitative evidence from novice biology teachers' classrooms. *Journal of Research in Science Teaching, 30*, 471–481.

Davies, J. R. (1995). *Interdisciplinary courses and team teaching: New arrangements for learning*. Phoenix: American Council on Education/Oryx Press.

De Jong, O., Van Driel, J. H., & Verloop, N. (2005). Preservice teachers' pedagogical content knowledge of using particle models in teaching chemistry. *Journal of Research in Science Teaching, 42*(8), 947–964.

Geddis, A. N. (1993). Transforming subject-matter knowledge: The role of pedagogical content knowledge in learning to reflect on teaching. *International Journal of Science Education, 15*, 673–683.

Geddis, A. N., Onslow, B., Beynon, C., & Oesch, J. (1993). Transforming content knowledge: Learning to teach about isotopes. *Science Education, 77*(6), 575–591.

Gess-Newsome, J., & Lederman, N.G. (1993). Preservice biological teachers' knowledge structures as a function of professional teacher education: A year-long assessment. *Science Teacher Education, 77*(1), 25–43.

Gess-Newsome, J., & Lederman, N. G. (Eds.). (1999). *Examining pedagogical content knowledge*. Dordrecht: Kluwer.

Goker, S. D. (2006). Impact of peer coaching on self-efficacy and instructional skills in TEFL teacher education. *System, 34*, 239–254.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Hasbrouck, J. E. (1997). Mediated peer coaching for training preservice teachers. *The Journal of Special Education, 31*, 251–271.

Hashweh, M. Z. (1987). Effects of subject-matter knowledge in the teaching of biology and physics. *Teaching and Teacher Education, 3*, 109–120.

Hashweh, M. Z. (2005). Teacher pedagogical constructions: A reconfiguration of pedagogical content knowledge. *Teachers and Teaching: Theory and Practice, 11*, 273–292.

Jang, S. J. (2006). The effects of incorporating web assisted learning with team teaching in seventh-grade science classes. *International Journal of Science Education, 28*(6), 615–632.

Jang, S. J. (2007). A study of the students' construction of science knowledge: Talk and writing in a collaborative group. *Educational Research, 49*(1), 65–81.

Jang, S. J. (2008a). The effects of integrating technology, observation and writing into a teacher education method course. *Computers in Education, 50*(3), 853–865.

Jang, S. J. (2008b). Innovations in science teacher education: Effects of integrating technology and team-teaching strategies. *Computers in Education, 51*(2), 646–659.

Jenkins, J., & Veal, M. L. (2002). Preservice teachers' PCK development during peer coaching. *Journal of Teaching in Physical Education, 22*(1), 49–68.

Jenkins, J., Garn, A., & Jenkins, P. (2005). Preservice teacher observations in peer coaching. *Journal of Teaching in Physical Education, 24*, 2–23.

Joyce, B. R., & Showers, B. (1982). The coaching of teaching. *Educational Leadership, 40*, 4–10.

Joyce, B. R., & Showers, B. (1995). *Student achievement through staff development: Fundamentals of school renewal* (2nd ed.). White Plains: Longman.

Joyce, B., & Weil, M. (1996). *Model of teaching* (5th ed.). Boston: Allyn and Bacon.

Koballa, T. R. (1992). Peering coaching: Capitalizing on constructive criticism. *The Science Teacher, 59*(6), 42–45.

Kohler, F. W., & Ezell, H. K. (1999). Promoting changes in teachers' conduct of student pair activities: An examination of reciprocal peer coaching. *Journal of Special Education, 33*(3), 154–165.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Publishers.

Lederman, N. G., Gess-Newsome, J., & Latz, M. S. (1994). The nature and development of preservice science teachers' conceptions of subject matter and pedagogy. *Journal of Research in Science Teaching, 31*, 129–146.

Lieberman, A. (1995). Practices that support teacher development: Transforming conceptions of professional learning. *Phi Delta Kappan, 76*, 591–596.

Little, J. W. (1993). Teachers' professional development in a climate of education reform. *Educational Evaluation and Policy Analysis, 15*, 129–151.

Loughran, J. J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Developing ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*, 370–391.

Louis, K. S., & Marks, H. M. (1998). Does professional community affect the classroom? Teachers' work and student experience in restructuring schools. *American Journal of Education, 106*(4), 532–575.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Dordrecht: Kluwer.

Marshall, K. (2005). It's time to rethink teacher supervision and evaluation. *Phi Delta Kappan, 86*, 727–735.

McAllister, E. A., & Neubert, G. A. (1995). *New teachers helping new teachers: Preservice peer coaching*. Bloomington: EDINFO Press.

McMillan, J., & Schumacher, S. (2001). *Research in education: A conceptual introduction* (5th ed.). New York: Addison Wesley Longman.

Mulholland, J., & Wallace, J. (2005). Growing the tree of teacher knowledge: Ten years of learning to teach elementary science. *Journal of Research in Science Teaching, 42*(7), 767–790.

Pierce, D., & Hunsaker, T. W. (1996). Professional development for the teacher, of the teacher, and by the teacher. *Education, 117*(1), 101–105.

Pugach, M., & Johnson, L. J. (1995). Unlocking expertise among classroom teachers through structures dialogue: Extending research on peer collaboration. *Exceptional Children, 62*, 101–110.

Ross, J. A., & Bruce, C. D. (2007). Teacher self-assessment: A mechanism for facilitating professional growth. *Teaching and Teacher Education, 23*, 146–159.

Sanders, L. R., Borko, H., & Lockard, J. D. (1993). Secondary science teachers' knowledge base when teaching science courses in and out of their area of certification. *Journal of Research in Science Teaching, 3*, 723–736.

Showers, B., & Joyce, B. (1996). The evolution of peer coaching. *Educational Leadership, 53*(6), 12–16.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*, 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1–22.

Skinner, M. E., & Welch, F. C. (1996). Peer coaching for better teaching. *College Teaching, 44*(4), 153–156.

Slater, C. L., & Simmons, D. L. (2001). The design and implementation of a peer coaching program. *American Secondary Education, 29*(3), 67–76.

Strauss, A. (1987). *Qualitative analysis for social scientists*. New York: Cambridge University Press.

Thijs, A., & van den Berg, E. (2002). Peer coaching as part of a professional development program for science teachers in Botswana. *International Journal of Educational Development, 22*, 55–68.

Valencia, S. W., & Killion, J. P. (1998). Overcoming obstacles to teacher change: Direction from school-based efforts. *Journal of Staff Development, 9*(2), 2–8.

Van Dijk, E. M., & Kattmann, U. (2007). A research model for the study of science teachers' PCK and improving teacher education. *Teaching and Teacher Education, 23*, 885–897.

Van Driel, J. H., Beijaard, D., & Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Teaching, 38*(2), 137–158.

Van Driel, J. H., De Jong, O., & Verloop, N. (2002). The development of preservice chemistry teachers' PCK. *Science Education, 86*, 572–590.

Vidmar, D. J. (2006). Reflective peer coaching: Crafting collaborative self-assessment in teaching. *Research Strategies, 20*, 135–148.

Chapter 9
Issues and Challenges in School-Based Assessment of Science Practical Work

Benny Hin Wai Yung

9.1 Introduction

The forms that examinations and assessment take are widely recognised as determinants of educational practice. In order to transform classroom practices, it is necessary to shift teachers' conceptions of assessment away from dominating notions of accountability and achievement to more holistic purposes of gathering evidence useful for informing teaching and learning practices (Shepard 2000). It was against such a background that the former Hong Kong *A*-level Biology Practical Examination was replaced by a school-based assessment scheme – the Teacher Assessment Scheme (TAS). For a similar reason, the Science Practical Assessment (SPA) scheme is implemented in Singapore to replace the former one-time practical test administered at the end of General Certificate Examination *O*- and *A*-level science courses.

Both TAS and SPA are designed to promote the investigative approach in teaching practical work (Yung 2006; Towndrow 2008). Hopefully, in so doing, this can enhance students' understanding of scientific concepts, motivate learning through hands-on activities and develop essential practical skills for laboratory investigations (Ministry of Education, Singapore 2002). Under the new assessment schemes, teachers are required to make their own decisions about the science practical skills they want to teach and assess during the academic years leading up to the public examinations. Teachers are given responsibility for designing 'everyday' and assessment tasks with accompanying scoring rubrics that fit their own teaching situations. In short, besides aiming for a more valid assessment of students' practical competencies, both TAS and SPA aim to 'liberate' the science curriculum by providing

---

B.H.W. Yung (✉)
Faculty of Education, The University of Hong Kong, Hong Kong, Hong Kong
e-mail: hwyung@hkucc.hku.hk

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_9,

teachers with more rooms to make pedagogic decisions of their own. As some advocates claim, school-based assessment can enhance teacher professionalism by widening their experience (Yung 2006).

Disappointedly, changes in policy do not always influence instructional practices as anticipated (Richardson and Placier 2001). This is especially the case for assessment reform as it relates to the formative aspects of assessment which is a topical and much-debated issue (Black and Wiliam 2003). The problem is further complicated by the intricate relationships amongst assessment, teaching and learning. Often, how the problem unfolds is very much dependent on the underlying interplay and intertwining variables within the specific context where the assessment takes place (Carless 2005). I would argue that teacher professionalism and their assessment competencies are two crucial factors in determining the success of any school-based assessment scheme.

To position my argument, I shall begin with a brief review of the literature on teacher professional development. This is followed by stories of teachers' experiences in implementing the assessment reforms in Hong Kong and Singapore. Though the stories have appeared in one form or another in various publications, re-telling and, in some cases, re-interpreting them in one go helps put the bits and pieces together to illuminate the issues and challenges involved. This paves way for a subsequent discussion on implications for teacher professional development. This chapter concludes with a call for more investment on teacher professional development in this area.

9.2 Teachers' Professional Development

The importance of continuing professional development for the teaching profession is increasingly acknowledged in countries throughout the world (Coolahan 2002). Research has consistently pointed to the need of addressing issues of teacher change, sustainability and understanding the impact of professional development programmes designed to support educational reforms (e.g. Fraser et al. 2007). Two broad and largely opposing approaches to teacher professional development are identified: one follows a short-term, training-based agenda that is usually conducted off-site by an external agent, and the other involves the adoption of a more continuous, situated and learning-based approach (Kennedy 2005).

Traditionally, information and new developments in education are passed onto teachers through workshops and short in-service professional development courses delivered off-site by external 'experts'. This approach is an efficient way to reach out to many teachers and raise their awareness of new pedagogies in a short period of time, focusing on technical aspects of the job rather than issues relating to values, beliefs and attitudes. Though suitable for information acquisition or learning procedural skills, research has shown that this approach is not effective and rarely leads to changes in classroom practice (Sprinthall et al. 1996). Moreover, such an approach could possibly result in the loss of teachers' professionalism and appreciation of the diversity of experiences of teachers', students' and school needs (Kennedy 2005). This is because teachers' voices are often silent in this approach of professional development, and, consequently, there is a danger that teachers might ignore, modify, abuse, misinterpret or distort the intention of educational policy changes as a result.

A radically different approach involves teachers initiating and enacting change for themselves in response to a variety of changes and influences both within and beyond their classrooms. In this approach, teacher learning is regarded as an ongoing process of sense-making relating to the new practices resulting from policy changes imposed on the teachers. Clarke and Hollingsworth (2002) argue that the school and classroom provide rich environments for teachers to enact emerging learning within their own context by undertaking 'professional experimentation'. This can help teachers make sense of their practical experiences, particularly those with positive outcomes. That, in turn, can lead to conceptual change and acceptance of new theories. They argue, as such, it would appear logical to position teacher professional development within the context of the teachers' workplaces.

Nonetheless, in situ professional development is not without its problems. As pointed out by Loughran and Gunstone (1997), even for teachers who are eager to improve their practices within their own schools, their enthusiasm in professional development work fetter once the research study has come to an end and the professional developer is no longer present in the school. Indeed, the motivating effect of interest and 'ownership' of the learning opportunity has been noted as a significant factor in teachers' professional development (Bell and Gilbert 1996). A question remains: How can educational innovation be sustained over the longer term?

In summary, despite the abundant professional development opportunities presented to teachers, those initiatives that overly focus on short-term gains might fail to account for teacher learning that is situated within a complex web of context-specific variables including politics, pedagogy and innovation (Rodrigues 2005). On the other hand, the issue of sustaining educational innovations remains problematic even for approaches that are context specific and customised to local circumstances. As will become apparent in the teacher stories presented below, my view is that sustained in situ teacher learning requires a lot more to be known about the web of factors that influence teachers and their classrooms as they attempt to make sense of educational policy reforms. Above all, teachers themselves need to be more proactive in their own professional development.

9.3 Stories of Teachers Implementing School-Based Assessment

Below are case studies which have been reported elsewhere. Details on data collection can be found in the original articles. In the main, these included classroom observations, coupled with relevant teacher interviews. Interpretive narrative accounts in the form of case reports will be used to convey the context of the studies and the knowledge that are implicit in the stories of the teachers. Except otherwise stated, all the teachers received minimal professional development training in school-based assessment mainly in form of one-off short training workshops or conferences that focused on technicalities of complying to the regulations of the assessment schemes. The presentation of the stories has been guided by following questions: Why are the teachers' actions and responses to the new assessment systems so different? What are the roles of different forms of professional development in helping teachers to understand and enact the assessment reforms?

To enable readers to better understand the issues and challenges faced by the teachers as well as my interpretation of the stories that follows, a brief introduction to the education systems in Hong Kong and Singapore will help. Both Hong Kong and Singapore have an examination-led education system. As a consequence, examinations determine the quality of the educational experiences of teachers and students. What transpires in the classroom is largely dictated by what happens in the public examination halls. The obsession with testing and examinations is vividly illustrated in the following quotation from a review of the Hong Kong education system (Choi 1999):

> In fact, students sometimes stop their teachers teaching certain topics or materials which are not in the [examination] syllabus. (p. 412)

A similar, if not worse, situation occurs in Singapore as described by Towndrow and his colleagues (2010, p. 121), 'Teachers are crucial elements in students' successes in these high-stakes tests. They are expected to implement and monitor compliance with standard operating procedures and deviance from published and unpublished approaches and norms is unexpected, unrewarded and risky'. In sum, an examination-oriented culture is firmly embedded both in Hong Kong and Singapore, and that examinations are stressful both for students and teachers. Everyone knows that there is much at stake.

9.3.1 Bob: They Are Learning While I Am Assessing Them

Bob, a teacher in Hong Kong, has 7 years of teaching experience. He is able to cope with the requirements of the TAS quite well. He is able to come to grips with the formative function of the assessment. He often initiates discussions with individual students during the course of the practical. In fact, he is mindful of the importance of interacting with students even at the lesson planning stage (Yung 2006):

> *One of my major considerations in selecting practical work for the TAS assessment is whether I can make use of the practical to induce some kind of discussion with my students and that they can learn through it … This is a very crucial part in their learning … So, they are in fact learning while I am assessing them.*

Sadler (1989) believes that assessment is truly formative only when it involves the student. As such, the judgements about the quality of students' responses can be used to shape and improve their competence by short-circuiting the randomness and inefficiency of trial-and-error learning. This is exactly what Bob was trying to achieve when he engages in active discussions with his students. One common feature in the discussion of Bob with his students is that he always responds to his students' queries with remarks and questions like, '*What do you think?*' '*What better procedure can you think of?*' or '*You think over yourself first. I will come back to you later*'. In a post-lesson interview, Bob mentioned the positive effect of the TAS on his teaching and the learning of his students:

> *In the past, I would point out their mistakes directly to them. Now, I have to remind myself to be conscious of this. Telling them directly is the fastest and simplest way, but it does not make them think. This is a good influence on both teaching and learning.*

This indicates that Bob has begun to realise the importance of not only providing feedback to students but also attending to the quality of the feedback, as Sadler (1998, p. 84) has pointed out, 'Formative assessment does not make a difference, and it is quality, not just quantity, of feedback that merits our closest attention. By quality of feedback, we now realise we have to understand not just the technical structure (such as its accuracy, comprehensiveness and appropriateness), but also its accessibility to the learner (as a communication), its catalytic and coaching value, and its ability to inspire confidence and hope'. In sum, Bob is able to find a handle or frame of reference outside the concrete situation of assessing his students by being '*conscious of not telling students the answers directly so as to make them think*'. He sees this as a good influence on both his teaching and his students' learning.

9.3.2 Carl: Interacting with Students Is an Unexplored Treasure

Carl, another Hong Kong teacher, has more than 20 years of teaching experience. Similar to Bob, there are a lot of discussions between Carl and his students during the TAS practicals. In addition, there are also a lot of discussions amongst students themselves, which is not observed in Bob's lessons. When asked why he often encourages students to discuss amongst themselves and whether this would create a dilemma for him in coping with the requirements of the TAS, Carl replied (Yung 2006):

> *This is a compromise to students' cultural habits of not wanting to be vocal. They are passive … I am aware of the conflict between teaching and assessment but there is no such formal statement about the Do's and Don'ts in the TAS Handbook. I think limited discussion won't affect their overall performance too much. Too much emphasis on assessment will hinder a lot of ideas flowing out. They have undergone the educational process. Is that really going to affect the fairness of the assessment?… The interaction amongst themselves and between us is an unexplored treasure. I have been encouraging them to speak up. But this has to be built up slowly step by step … I have faith in my students …*

More classroom episodes of how Carl tries to tap into the 'unexplored treasure' of interacting with his students can be found in Yung (2006). When asked if frequent interaction with students would affect the fairness of the assessment, Carl's view was:

> *This is what science education is about. TAS never prohibits teachers from responding to questions raised by students. Students' overall performance will not be affected by just one*

> *or two points which they might have discussed with the teacher or their classmates. Differentiation [in their capabilities] will be reflected in their overall performance in the reports … The idea of the TAS is to integrate assessment with teaching and learning.*

Very clearly, Carl's way of implementing the TAS is very much related to his 'scaffolding' view of learning (Shepard 2005), in which the teacher should try to provide a stimulating environment and guide his students towards learning 'step by step'. In sum, Carl, like the previous teacher, Bob, seems to be fairly good at integrating assessment with teaching and learning. That is, both of them, like a few other teachers in Yung's (2006) study, understand the TAS not only as an assessment reform but also one with a pedagogical dimension including the promotion of investigative practical. For these teachers, professional development in the format described in the case below is likely to help in achieving the reform goals.

9.3.3 Departmental Professional Dialogue on Laboratory Task Design

To prepare teachers for the SPA in Singapore, Towndrow et al. (2010) conducted a teacher development study. Over a period of 20 weeks, three researchers and four upper secondary biology teachers in a science department of a secondary school had a series of professional dialogues about how to incorporate enquiry into commercially published workbook investigations. The aim was to help the teachers to design, implement and evaluate practical assessments that could be used for the SPA.

The group began with turning a cookbook-type practical on the action of diastase on starch into an investigation which can help students understand the purposes of procedure and the possible sources of experimental error. Discussion then turned to planning the next practical which investigates the effect of pH on catalase (an enzyme which catalyses the breakdown of hydrogen peroxide into water and oxygen).

The recommended procedure involved the use of a data logger to determine the rate of reaction at different pH values. In the trial run session, the materials and equipment for the data logger experiment were prepared and set up following the workbook, but some items of glassware and stoppers were not exactly the same. Although the workbook instructions appeared simple enough, the teachers and researchers had difficulty conducting the experiment. Due to the vigorous enzymatic reaction, it was not possible to create an airtight condition in the experimental set-up (with a plasticine improvisation) for collecting the oxygen released and then passing it into another beaker of water, where a dissolved oxygen sensor was installed to measure the changes in dissolved oxygen content. (Details about the problematic set-up can be found in Towndrow et al. (2010).)

Sensing trouble if the same thing were to happen in class, the researchers and teachers engaged in troubleshooting immediately, first by using half the volume of reactants, hoping that the rate of reaction would be less vigorous, but failed. Attention was then turned to the equipment and, in particular, to whether the dissolved oxygen sensor was being used correctly and how accurately it was detecting the oxygen that was evolved. After several attempts, much discussion and an impromptu search of the World Wide Web, the idea was tabled to measure the oxygen evolved directly instead of waiting for it to dissolve. Eventually, it was realised that more needed to be known about the mechanics of the dissolved oxygen sensor.

Subsequently, it was known from a supplier of the data logger (contrary to the instructions in the students' workbook) that the dissolved oxygen sensor was only for point sampling (as it consumes oxygen when used continuously). Armed with this knowledge, a simpler experimental set-up was devised using an oxygen gas sensor from a different manufacturer. This workaround was successful, and everyone agreed that measuring gaseous exchange was easier and better than dissolved oxygen. It was also concluded that the inaccuracies in measuring dissolved oxygen were compounded by the fact that the solubility of oxygen in water is not high. One of the teachers commented how enlightened she was after having gone through the cooperative process of troubleshooting and thinking about the experiment.

The professional dialogue, experimentation and learning that took place in the planning of the *Effect of pH on Catalase* task marked the beginning of a curriculum development community of practitioners in the school's science department. Their dialogue continued in jointly correcting and modifying the students' laboratory sheets in ways that could provide students with sharper learning foci as well as pinpointing for themselves the specific laboratory competencies that could be assessed in relation to the SPA.

To conclude, it is no doubt such professional developmental work for teachers is necessary if the desired pedagogic outcomes of TAS/SPA are to be achieved. However, for teachers described below, this kind of professional development activities may not be adequate enough in preparing them for the new demand imposed on them both as a teacher and an assessor.

9.3.4 John: I Must Be Fair

John, one of the Hong Kong teachers in Yung's (2006) study, has 20 years of teaching experience. In implementing the TAS, John is preoccupied with the issue of fairness as exemplified in the following episodes. In the first episode, it is at the beginning of a TAS practical. John is inviting questions from the class after distributing the lab manual and allowing them some time to read:

> *Any questions before we start? Any questions, please? [There was no question from the students. John then said again.] Come on, any question? Free of charge! Marks will not be deducted. Come on. Any question?* [Again, there was no question from the students. John, then, signalled the class to begin their work.]

As suggested by Bell and Cowie (2001), assessment takes place in the social space of the classroom. It is a social practice, constructed within the social and cultural norms of the classroom. It is shared. Why was there no question from the students? The amount of help provided to students might have constituted one of John's criteria for assessing his students' practical competence. Such an assessment criterion had been reiterated again and again by John during his prior lessons. Thus, John's stating that 'marks will *not* be deducted' at the beginning of the lesson might just have reinforced students' perception that 'marks *will* be deducted' in other situations if the teacher does not invite questions from them. As will be evident in subsequent episodes, students in general do not like this idea. Often, they prefer to proceed without assistance even though they realise that they may not be able to generate an effective response to the practical task assigned.

In fact, it is very rare for John to invite questions from the class during the TAS practicals. This occurs only at the beginning of the practicals, where the intent is mainly to sort out problems related to provision of apparatus and materials. In the actual course of the TAS practicals, John is reluctant to answer students' questions, as illustrated by the following episode:

Student: *I have a question but will marks be deducted?*
John: *You ask it first.*
Student: *Chee! I don't want to ask then.*
John: *If I am going to deduct marks, I will tell you first.*
Student: *If I ask you the question, but then you tell me afterwards that marks have been deducted, I will be very depressed.*
John: *Just go ahead and ask me. And you will know what the outcome would be.*
[The student then asks the question.]
John: *I have to deduct marks from you if I answer you this question. Therefore, I am not going to answer this question. You think about it yourself.*
Student: *Are you really not going to deduct any marks from me at all?*
John: *Go back and do you work quickly.*

The reason behind John's decision not to answer the student's question is that, 'I must be fair. I can't answer some students' questions but not the others … What bothers me is that, suppose I am going to answer students' question, how many questions should I entertain, and to what extent? This is the most difficult part. If there was no TAS, I would then have given her a definite answer …'

Clearly, John is caught in a dilemma of trying to be fair to all students on one hand and trying to solve their problems on the other. Obviously, teaching and assessment have become polarised; teaching has given way to assessment, and the formative function of assessment is lost. The requirement to submit the TAS marks to the public examination body for certification purposes has framed the way in which John interprets the assessment reform. He has drawn on his previous experience and understanding of what assessment is about in order to make sense of the changes and to make decisions about how he should implement the TAS, as he put it:

> *TAS is certainly an assessment … the hard fact is that I have to submit the marks to Hong Kong Examinations Authority (HKEA) … If you tell students that marks are not important, just to relax and try, students just would not believe in what you say, … They know what is going on. You just can't fool them.*

Hence, it is not surprising if the introduction of TAS is regarded as purely for the purpose of improving the validity and reliability of the assessment. In fact, this is not an unreasonable assumption for teachers to make when the reform is initiated by the HKEA – the public examining body. No wonder, based on such a mindset, the classroom situation in which practical work occurred is that of a formal assessment. Though this does not mean that the teacher cannot help the students, any assistance given would be an integral part of the assessment process, and would result in the deduction of marks. In other words, the teacher is explicitly acting under the authority of HKEA, as an extension of the examination procedures. This aspect of TAS work has been a source of tension for many teachers in Hong Kong (Yip and Cheung 2005) such as John. For these teachers, the intentions that the assessment reform would broaden the curriculum and improve the quality of teaching and learning have drifted quietly into the background.

9.3.5 Sophia: No Talking

Sophia is a biology teacher in Singapore, with just 2.5 years of teaching experience. In the following episode, she is preparing her secondary one (13-year-old) class for a forthcoming summative SPA task aimed at assessing students' individual practical skills. She wants this 'practice' experiment to be conducted under mock exam conditions so as to prepare students for the novel assessment system. Before the students begin work, Sophia issues the following guidance to the class:

> *All right, now this is an exam question so when you are going to do your experiment there will be no talking. Okay, quiet. Since this is individual work, you have to be resourceful when collecting your own apparatus. So you only share your water bath, the Bunsen burner and tripod stand. You take you own boiling tubes. Any questions? You can share your water bath. And Bunsen burner and lighter. That's all. Alright. No more talking. You only share water bath, lighter and Bunsen burner. Cannot share wire gauze. So anything that requires a water bath you share. But anything else, boiling tubes, you have your own. White tile your own. Forceps also have your own. Any more question? … Alright? So you will have one period, which is about 45 minutes to do this experiment. You may begin now. Read your experiment. Class, glass rods are in front. Forceps are in front. You don't share any of them.* [After 3 minutes] *You don't seem to understand this is an assessment. Nobody should be talking. Not even to your partner.* (Tan and Towndrow 2009, p. 63)

Clearly, in stressing the importance of 'no talking', 'quiet', 'individual work', 'no more talking', 'nobody should be talking', Sophia has closed down the opportunities for discussion, peer learning and collaboration to occur. It has also restricted her scope to provide feedback that can help her students improve their learning.

Arguably, in terms of how assessment reform practices have eaten into the curriculum time which could have been used for teaching and learning purposes, Sophia's case is even more disappointing than John's case reported above. In both cases, instructional time is reduced as some lessons are reserved for carrying out the school-based assessment. The problem is worsened in Sophia's case, with additional instruction time being curtailed for 'practice' experiments to be conducted under mock exam conditions so as to prepare students for the summative SPA.

In summary, the cases of John and Sophia show that genuine improvements in the effectiveness of learning actually require a major rethink about the way that assessment is used. This rethink needs to be based on a careful analysis of how assessment can promote individual learning. In particular, teacher development activities aimed at re-constructing their ideas about the role of school-based assessment in the educational reform and helping them to develop strategies for utilising the outcomes of assessment in formative and educative respects are imperative. To this end, the following two cases from Hong Kong (Yung 2006) are illustrative.

9.3.6 Ivor: A Police Officer Afraid of Being Scolded by His Superior, and Dawn: I Am More Liberated Now

Ivor has more than 15 years of teaching experience. Not only does he refrain from offering help to individual students during the TAS practicals, like John and Sophia, he also does not allow students to discuss with their peers. Additionally, he adopts a 'picky and fault-finding' attitude when assessing his students as per his description of himself:

> *I fear that the exam board would say that my marking is too lenient. I'd rather deduct marks from my students without any special reason … I have to keep their marks low. I had to be very picky and fault finding with students. Otherwise they might get a very high mark, so high that the exam board would not believe in it. I had to behave like a policeman who had to grasp every chance to give out the assigned quota of illegal parking tickets in order not to be scolded by the superior … It is really unfair to them [the students].*

Embodied in this metaphor – a police officer afraid of being scolded by the superior – is the perception that TAS is a part of the high-stake public examination, and that the teacher is held accountable by the examination board for carrying out the assessment properly. Also expressed in this metaphor is a strong feeling of insecurity. That is, fear of being scolded by the superior for not being able to accomplish the job assigned. This illustrates vividly how Ivor has submitted passively to the TAS regulations, even though he judges them to be misguided; as reflected in his tone and expression such as 'it is really unfair to them'. There is clearly a sense of powerless and resignation as further revealed in the following interview excerpt:

> *I worry a lot about how much I should discuss their experimental proposals with them [the students]. If I tell them too much, I may be violating the TAS regulations. So, the best thing is that I tell them nothing, I am sort of trying to protect myself as far as possible. I just don't care whether students understand or not.*

In sum, Ivor perceives the introduction of TAS as imposing severe constraints upon his professional autonomy to such an extent that he would rather 'protect himself' than look after students' learning. Clearly, teacher professionalism is severely compromised as Ivor struggles to make sense of his changing roles as both an assessor and a teacher. This is in contrast to the next teacher, Dawn, who is now able to come to grips with the dual role required of her to be a teacher and an assessor, though only after going through a rather painful learning process:

> *I don't want those terrible things in the first year of the TAS to happen again. At that time, I was not familiar with the scheme. Students and I were putting pressure on each other. They*

> *were neurotic and so was I. That is not a good way to learn … I don't want to use marks to threaten them … I think it is something to do with your attitude. Whether you really want to help the students …*

Dawn is a lively and friendly teacher in her early 30s. Unlike Ivor, Dawn does not avoid giving assistance to students if she deems it necessary. She upholds her belief that the teacher's role is to assist students' learning and that the assessment requirements should only be of secondary consideration in the process, as she put it:

> *If I don't do this, how are they going to learn? You know. I can deduct marks from them depending on the amount of help offered … Or, if I find all of them don't know how to proceed, I can just delete that particular assessment criterion from the assessment checklist … In the past, I emphasized asking all students to follow a standard method so that I could grade them more easily (using a common checklist). Now, I allow them to work with their own methods. Gradually, I have come to realize that there are bound to be variations in their methods. It's okay as long as I can make adjustments in assessing it. There can be different kinds of possible adjustment there.*

Clearly, Dawn is 'in control' of the teaching-learning situation inside her classroom while Ivor is very much 'controlled' by the TAS regulations. In other words, Dawn is adept at finding spaces in which she could manipulate the TAS requirements with her own professional judgement. Nevertheless, this realisation of the flexibility provided by the TAS did not come with the introduction of the TAS but resulted from the experiences she has gained over the years:

> *In the past, I felt very much constrained by the TAS. Now, I feel that I am set free again. This is an evolution really. I have evolved … In the first year of the TAS, … I thought that it was something like an examination. I adopted a very strict attitude on every single item.… I had to work very carefully because this is an examination. In those days, most teachers had a very bad feeling towards TAS. I am much more liberated now … I don't feel so constrained now…*

Dawn attributed her evolution into taking on 'a more liberated view' of interpreting the TAS regulations in subsequent years to her becoming a TAS coordinator herself. She attributed much of her professional growth in this area to her interactions with like-minded colleagues during the TAS coordinator meetings. These have provided opportunities for her to find out what practising the reform ideas may involve and afford her an opportunity to gain the insights of others on the practical problems of putting the ideas into actual practice. This lends support to the important role played by smaller collegial groupings in teachers' professional development and teachers' enactment of the reform as illustrated by the Singaporean case described above – the departmental professional dialogue on laboratory task design.

More importantly, Dawn's case also suggests that teachers are able to exercise control of their own teaching by adopting a critical stance to policy change. However, as pointed out by Harlen (2005, p. 210), 'It takes a good deal of support – and courage – for teachers to turn round their practices from being test-oriented to being learning-oriented'. Indeed, it points to the need for greater teacher support and more professional development in this respect than is currently available. This presupposes skilled and confident teachers who need time and space to reflect and to question values. Short courses which focus on survival strategies and 'tips for teachers' are unlikely to stimulate the quality of thinking and reflection which are seen as necessary conditions for change and development. If teachers are to regain their professional confidence and play a significant role in curriculum reform, there are implications for teacher education. In particular, they need to engage with changes, rather than be taken over by them. In order to do that, they need to understand the origins and nature of the changes and their own responses to them.

9.4 Implications on Teacher Professional Development

As evident from the above cases, teacher professionalism and their assessment competencies are crucial issues that need to be addressed if we are to achieve the reform goals. In Singapore, with the help of researchers, some teachers work together, discuss, clarify and refine their practices as they make decisions about what to teach and assess; whereas in Hong Kong, some teachers, like Dawn, take a critical stance towards the new policy and learn from their own experiences in order to build their confidence. With the same policy initiative, one group of teachers (e.g. John, Sophia and Ivor) seems to focus more on the technicalities of complying with the requirements imposed on them while the other group of teachers (e.g. Bob, Carl and Dawn) has their professional consciousness of what they think are best for their students provoked so that their practices will be transformed. There may be important lessons here for other countries attempting to support the implementation of assessment policy reforms through teacher professional development programmes.

Certainly, teachers who are inexperienced in teaching and assessing science using the investigative approach will require help like those received by the Singaporean teachers described above. More importantly, all teachers, regardless of their experience, need to be helped to move beyond the technicalities of assessment schemes towards identifying, questioning and reformulating educational practices more generally. They need to be provided with opportunities and help to reflect on their own practices in relation to the demands imposed on them by the policy change. In Singapore, Towndrow (2008) reported a successful example of a one-year, one-to-one teacher-researcher collaboration, where the teacher was able to take ownership of the assessment reform by adopting a critically reflective stance. The interaction between the researcher and the teacher was predicated on the premise that teachers need to move beyond the technicalities of assessment scheme towards identifying, questioning and reformulating educational practices more generally. Pertinent to the outcome was also the researcher's role 'to probe and unsettle practice thoughtfully' (Towndrow 2008, p. 907). However, in reality, it is rare for individual teachers to have such an opportunity to interact with an intently third party for such an extended period of time. As aptly pointed out by Baker (2007), amongst many other characteristics, sustainable educational innovations are marked by their essential non-reliance on the continued presence of individual change initiators. In view of this, three alternatives where teachers themselves are expected to play a more proactive role in their own professional development are offered below.

First, readers may recall the metaphor – a police officer afraid of being scolded by the superior – used by Ivor in describing his actions in TAS. There are plenty of accounts of teachers' use of metaphors in describing their assessment actions (e.g. Yung 2006). It has been suggested that metaphors are ways to begin conversations about teaching and learning and to facilitate reflection on and in practice (Tobin and Tippins 1996). Hence, as I have argued elsewhere (Yung 2001), the exposure of this use of language ought to become the first stage of any attempt to improve teachers' assessment practice. Specifically, the teachers can be helped to make sense of the metaphors they used to describe their action by identifying systematic correspondences or mappings between elements of the 'target' and the 'source'. The 'target' being the novel and difficult to conceptualise concept – which, in the above metaphor, is the teacher's role in the TAS/SPA. The source being the more accessible and familiar concept in the teacher's prior knowledge (e.g. what it takes for being a police officer who are afraid of being scolded by the superior). In the course of making these mappings and reflecting on them, teachers can better understand their own teaching beliefs and roles through the metaphors they craft to identify their role within the new assessment schemes.

After the teachers have become metacognitively more aware of their own beliefs and actions through examining their own metaphors for functionality, they can then be offered with alternative metaphors for consideration and comparison with their own (refer to Yung 2001 for more examples of metaphor, including the 'driving license examiner' or the 'companion' metaphor). Lastly, the teachers can be helped in identifying actions in relation to TAS/SPA that are consistent with the alternative metaphors. In sum, the process of teacher change might be initiated through a three-stage process: (1) awareness, (2) comparison with alternatives and (3) identifying actions that are consistent with the alternatives. Most importantly, the teachers themselves must undertake such a learning process.

A second way of preparing teachers for the new assessment reform is case sharing. Instead of focusing on one's own practices, teachers can begin with reviewing practices of their peers. For instance, some of the cases reported in this chapter contain information about concrete examples of teachers' educational practices, their concerns and some of the methods used to solve practical problems. It also delves into their personal beliefs behind their practices, views which were built over an extended period of day-to-day teaching. These can serve as good illustrations and models in which other teachers can compare their own practice and learn. These cases, though in a sense idiosyncratic to the individual teachers with their own contextual variables, do contain many teaching characteristics which are generic, just as there were some common threads in the beliefs and thinking of the teachers. In considering these cases, and then comparing, reflecting and evaluating their own practices, teachers may come to see beyond the specificity and idiosyncrasy of the practices and use them to uncover their own professional consciousness. This can help the teachers to re-organise their own belief systems and to re-direct their professional consciousness in relation to their own teaching context (Yung 2002).

I believe that the case studies reported in this chapter and other relevant sources (e.g. Yung 2006) constitute a useful source of curriculum materials for teacher professional development courses in the areas of school-based assessment of practical work. These case reports could be helpful to all teachers, whether experienced, newly qualified or in training, in the following ways as suggested by Black and Atkin (1996):

- As a source of models of practice to apply and test in the classroom
- As examples of practice that can be compared to the teachers' existing practice
- As a set of ideas to be debated upon and to act as a springboard to reflection on teachers' existing practice

These concur with Putnam and Borko's (1997) suggestion that case teaching is particularly appropriate in preparing teachers for reform-based teaching. This is because it increases the opportunities for teachers to experience workable alternatives to conventional practice in actual classroom settings, which otherwise is likely to be quite limited.

The third alternative is a variation to the previous one, replacing the written cases by video cases. In our recent studies (Cheng et al. 2010; Yung et al. 2007), we found that pre-service teachers can become cognizant of their changing conceptions of good science teaching by reflecting on the same set of case videos progressively at three different points in time during a 1-year teacher education course. We contend that similar professional development activities can be designed using video cases of school-based assessment to prepare teachers for reform-based teaching and developing them as reflective practitioners. This suggestion is also supported by evidence from a recent literature review on the use of video for effective teacher professional development (Yung et al. 2010). In particular, it is stressed that teachers can view and reflect on the video from their own perspectives instead of being guided to look at the case from the case writer's perspective. In other words, this would demand the teachers themselves to take up a more proactive and critical stance in their own professional learning to bring some changes in their practice of assessment.

9.5 Conclusion

To conclude, successful implementation of school-based systems of science practical work assessment requires teachers to play a directing role in aligning curriculum and pedagogy in their classroom. Teachers need to be 'in control' of the teaching-learning situation rather than being 'controlled' by the assessment requirements imposed on them. To achieve this goal, teachers need to be helped to move beyond the technicalities of assessment schemes towards identifying, questioning and reformulating educational practices by adopting a critical stance. They need to be provided with opportunities and help to reflect on their own practices in relation to the demands imposed on them by the policy change. Hence, a major investment in teacher professional development in this aspect is vital. Otherwise, this would be grossly unfair to all parties concerned – teachers and students alike!

References

Baker, E. L. (2007). Principles for scaling up. In B. L. Schneider & S–. K. McDonald (Eds.), *Scale-up in education: Ideas in principle* (Vol. 1, pp. 37–54). Plymouth: Rowman & Littlefield.

Bell, B., & Cowie, B. (2001). *Formative assessment and science education*. Dordrecht: Kluwer.

Bell, B., & Gilbert, J. (1996). *Teacher development: A model from science education*. London: Falmer Press.

Black, P., & Atkin, J. A. (1996). *Changing the subject: Innovations in science, mathematics and technology education*. London: Routledge.

Black, P., & Wiliam, D. (2003). 'In praise of educational research': Formative assessment. *British Journal of Educational Technology, 29*(5), 623–637.

Carless, D. (2005). Prospects for the implementation of assessment for learning. *Assessment in Education, 12*(1), 39–54.

Cheng, M. W., Wong, S. L., Yung, B. H. W., & Hodson, D. (2010). Mediating inquiry: Using videos of exemplary teaching in pre-service teacher education. In O. Kwo (Ed.), *Teachers as learners: Critical discourse on challenges and opportunities* (pp. 109–132). Hong Kong: Comparative Education Research Centre (CERC), HKU/Springer.

Choi, C. C. (1999). Public examinations in Hong Kong. *Assessment in Education, 6*(3), 405–417.

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947–967.

Coolahan, J. (2002). *Teacher education and the teaching career in an era of lifelong learning* (OECD Education Working Paper, Number 2). Paris: Education Directorate, OECD. Available online at http://www.oecd-ilibrary.org/education/teacher-education-and-the-teaching-career-in-an-era-of-lifelong-learning_226408628504. Last accessed on 20 May 2011. doi: 10.1878/19939019.

Fraser, C., Kennedy, A., Reid, L., & Mckinney, S. (2007). Teachers' continuing professional development: Contested concepts, understandings and models. *Journal of In-service Education, 33*(2), 153–169.

Harlen, W. (2005). Teachers' summative practices and assessment for learning – Tensions and synergies. *Curriculum Journal, 16*(2), 207–223.

Kennedy, A. (2005). Models of continuing professional development (CPD): A framework for analysis. *Journal of In-service Education, 31*(2), 235–250.

Loughran, J., & Gunstone, R. (1997). Professional development in residence: Developing reflection on science teaching and learning. *Journal of Education for Teaching, 23*(2), 159–178.

Ministry of Education, Singapore. (2002). *Curriculum planning and development division*. Intranet Website. Retrieved August 15, 2005, from http://intranet.moe.edu.sg/cpdd/

Putnam, R. T., & Borko, H. (1997). Teacher learning: Implications of new views of cognition. In B. Biddle, T. L. Good, & I. F. Goodson (Eds.), *International handbook of teachers and teaching* (Vol. II, pp. 1223–1296). Dordrecht: Kluwer Academic Publishers.

Richardson, V., & Placier, P. (2001). Teacher change. In V. Richardson (Ed.), *Handbook of research on teaching* (4th ed., pp. 905–947). Washington, DC: American Educational Research Association.

Rodrigues, S. (2005). *A model of teacher professional development: The partnership in the primary science project*. New York: Nova Science.

Sadler, R. (1989). Formative assessment and the design of instructional systems. *Instructional Science, 18*, 119–144.

Sadler, R. (1998). Formative assessment: Revisiting the territory. *Assessment in Education, 5*(1), 77–84.

Shepard, L. A. (2000). The role of assessment in a learning culture. *Educational Researcher, 29*(7), 4–14.

Shepard, L. A. (2005). Linking formative assessment to scaffolding. *Educational Leadership, 63*, 66–70.

Sprinthall, N. A., Reiman, J., & Theis-Sprinthall, L. (1996). Teacher professional development. In J. Sikula (Ed.), *Handbook of research on teacher education* (2nd ed., pp. 666–703). New York: Macmillan.

Tan, A. K., & Towndrow, P. A. (2009). Catalyzing student-teacher interactions and teacher learning in science practical formative assessment with digital video technology. *Teaching and Teacher Education, 25*, 61–67.

Tobin, K., & Tippins, D. (1996). Metaphors as seeds for conceptual change and improvement in science teaching. *Science Education, 80*(6), 711–730.

Towndrow, P. A. (2008). Critical reflective practice as a pivot in transforming science education: A report of teacher-researcher collaborative interactions in response to assessment reforms. *International Journal of Science Education, 30*(7), 903–922.

Towndrow, P. A., Tan, A.-K., Yung, B. H. W., & Cohen, L. (2010). Science teachers' professional development and changes in science practical assessment practices: What are the issues? *Research in Science Education, 40*, 117–132.

Yip, D. Y., & Cheung, D. (2005). Teachers' concerns on school-based assessment of practical work. *Journal of Biological Education, 39*(4), 156–162.

Yung, B. H. W. (2001). Examiners, policeman and students' companion: Teachers' perceptions of their role in an assessment reform. *Educational Review, 53*(3), 251–260.

Yung, B. H. W. (2002). Same assessment, different practice: Professional consciousness as a determinant of teachers' practice in a school-based assessment scheme. *Assessment in Education, 9*(1), 101–121.

Yung, B. H. W. (2006). *Assessment reform in science: Fairness and fear*. Dordrecht: Springer.

Yung, B. H. W., Wong, S. L., Cheng, M. W., Hui, C. S., & Hodson, D. (2007). Tracking pre-service teachers' changing conceptions of good science teaching: The role of progressive reflection with the same video. *Research in Science Education, 37*(3), 239–259.

Yung, B. H. W., Yip, V. W. Y., Lai, C., & Lo, F. Y. (2010, February 15–16). *Towards a model of effective use of video for teacher professional development*. Invited presentation in the International Research and Development Seminar on Continuing Professional Development for Science Teachers held in York University, UK.

Chapter 10
Creative and Co-operative Science and Technology Education Course: Theory and Practice in Finnish Teacher Education Context

Ossi Autio and Jari Lavonen

10.1 Introduction

Previous studies have suggested different ways of emphasizing creative problem solving in small groups (e.g. Grabinger 1996; Dooley 1997; Hill 1999). A common feature of these approaches is to place students in the midst of a realistic, ill-defined, complex and meaningful problem, which has no obvious or correct solution. Students work in teams, collaborate and act as professionals and confront problems as they occur – with no absolute boundaries. Although they might receive insufficient information to solve problems, the students must settle on the best possible solution by a given date. This type of multistaged process is characteristic of effective and creative problem solving. According to Fischer (1990), the stages may include:

1. Formulating the problem
2. Recognition of facts related to the problem
3. Goal setting – ideation or generating alternatives
4. The evaluation of ideas
5. Choosing the solution
6. Testing and evaluating

When problem solving is creative, the ideas or products produced during the problem-solving process are both original and appropriate (Fisher 1990). For such purposes, various idea-generation techniques or ideation models are valuable (Smith 1998). The number of alternative solutions is important because the best way to come up with good ideas is to have plenty of choices (Parker 1991).

O. Autio (✉) • J. Lavonen
Department of Teacher Education, University of Helsinki, Helsinki, Finland
e-mail: ossi.autio@helsinki.fi

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_10,

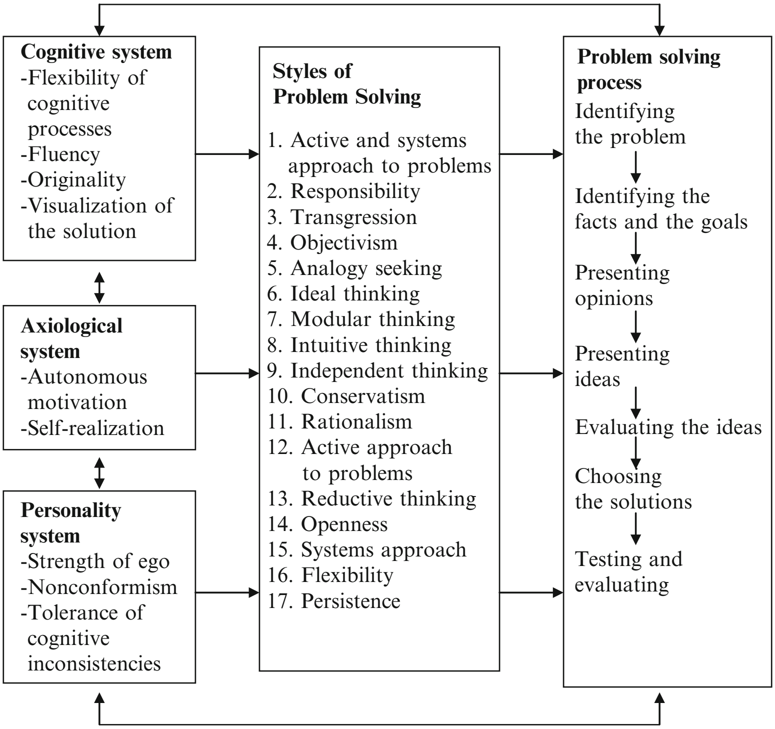


Fig. 10.1 Simplified model of the elements in the creative problem-solving process and the interaction of personal factors and styles of problem solving

Consequently, the outcome of the creative problem-solving process depends largely on the creative processes and styles of problem solving that have been learned and applied (see Fig. 10.1). In addition, there are factors of attitude (interest, motivation and confidence), cognitive ability (knowledge, memory and thinking skill) and experience (familiarity with the content, context and strategies) that influence problem-solving processes (Fisher 1990). For example, non-judgemental positive feedback and the acceptance of all ideas, even those which are absurd or impractical, are important in all creative and co-operative group processes (Higgins 1994). There should be sufficient encouragement for free ideation sessions. Evaluative critique should be given after the session has finished.

According to Strzalecki (2000), we can identify certain factors related to individuals' personal abilities and different styles of problem solving. In practice, the process of problem solving is very complicated and consists of many abstract concepts that cannot be defined completely and precisely. In Strzalecki's simplified model (Fig. 10.1), the various psychological domains connected with creative problem solving are concretised through the use of less abstract constructs. According to the model, the problem-solving process is based on the partly subconscious use of the cognitive, axiological and personality systems. If these systems do not help to find a perfect solution for a particular problem, an individual will try to find another solution by using different styles of problem solving. This simplified model of the elements in the creative problem-solving process and the interaction of personal factors and styles of problem solving is presented in Fig. 10.1.

10.2 The Creative and Co-operative Science and Technology Education Course

The plan for the creative and co-operative science and technology education course was based on the assumption that co-operative and creative problem solving would be valuable for developing a premium science and technology education study module for primary school teacher education. The goal of the course was to introduce our student teachers at the University of Helsinki to teaching methods that they could use to help pupils work co-operatively when they solve problems and make decisions during science and technology education teaching at their own schools.

As part of the course, the student teachers were asked to compose, plan and autonomously create an innovative new technological product. It could be a functioning piece of equipment or toy, system or process related to such themes as levers, crankshafts, gearwheels or moving and flying objects. Figure 10.2 presents a typical kind of product created in this exercise.

At the beginning of the course, the student teachers attended 2 h of lectures and demonstrations about creative problem solving. The sessions addressed different idea-generation techniques, such as brainstorming and analogous thinking. In addition, the student teachers became familiar with the theme through websites (Lavonen and Meisalo 2001) that presented problem-solving models and idea-generating techniques.

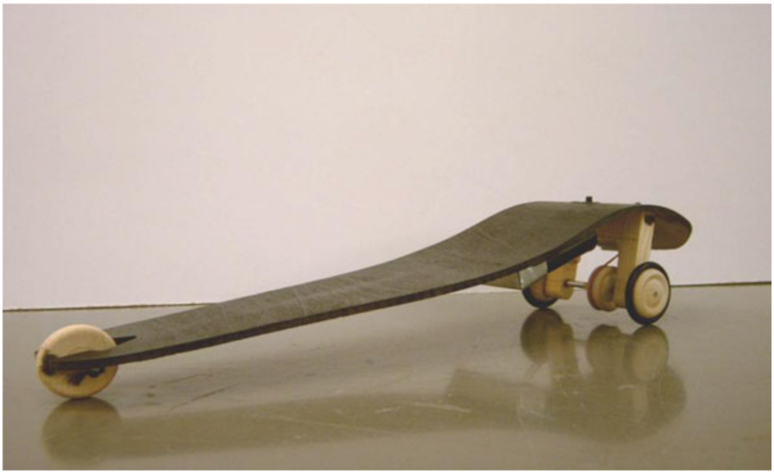


Fig. 10.2 An example of a technological product: a motorized mini roller board

The Problem: How to design a moving vehicle			
Facts: * Time limit * Electricity * Mechanics * Toy	**Opinions:** * Beautiful * Simple enough * Do we have enough skills? * Recycling material	**Goals:** * Useful * Moving vehicle * Modern * Must finish in time	**Visions:** *Artistic *Best seller *Creative
Approach A: Flying **Idea A1:** Airplane + Traditional + Interesting + Many options ? Does it fly? **Idea A2:** Helicopter + Not so usual + Innovative + Interesting + Exciting ? Is it flying **Idea A3:** Air balloon + Can really fly + Learn physics	**Approach B:** A car **Idea B1:** Police car + Easy to make + Kids like it + Interesting ? How to put something unusual **Idea B2:** Ambulance + Lights fit well with the idea + Interesting + Exciting ? How to get lights blinking **Idea B3:** Fire truck + Exciting	**Approach C:** A Ship **Idea C1:** Titanic + Easy + Traditional + Motivating story ? How to put something unusual **Idea C2:** Wing wheel + Innovative + Mechanics fit well + Interesting ? How to manage in time **Idea C3:** Submarine + Exciting + Periscope ? Does it really work?	**Approach D:** Stories **Idea D1:** Time machine + Historical perspective + Exciting + Innovative ? How to manage in time **Idea D2:** UFO + Innovative + Lights fit well + Futuristic perspective ? Mechanics **Idea D3:** Cows flying + Innovative + Not traditional ? How to keep in the air

Fig. 10.3 An example of the planning process expressed by an Overall Mapping of a Problem Situation (OMPS) constructed during the creative phase

The different abilities and skills needed in creative problem solving (e.g. creative, social and personal) and the ways to establish a creative and open atmosphere were discussed during the sessions. The sessions were followed by a 4-h workshop in which the students worked in small groups. To help the student teachers become familiar with problem-solving and decision-making processes, ideation techniques and the evaluation of ideas, we included a practical problem-solving model in the ideation process by introducing the Overall Mapping of a Problem Situation (OMPS) method (Sellwood 1991). In the workshops, the student teachers became familiar with the OMPS method by using it to plan the construction of a bridge or tower with newspapers.

During the planning phase of the project (4–8 h), groups of 3–4 students worked in 24 collaborative teams, where they generated a map of the creative process (Fig. 10.3). During this process, the student teachers had to find, formulate and specify the problem, and recognize the facts (certain rules and content that must be included in the course) and opinions related to the problem. Next, the teams set the problem or team assignment in a cogent phrase, such as the following: How can an interesting electric toy be constructed? In addition, the student teachers were required to set the goals and vision (ideal performance). Then, the student teachers had to create suitable approaches to solving the problem and generate problem-solving alternatives.

Every alternative idea was subsequently supported by presenting at least three positive reasons for its adoption (marked with + in Fig. 10.3). Non-judgemental, positive feedback and the acceptance of all ideas, even those which were absurd or impractical, were held as an important rule during all group problem-solving processes to generate various creative alternatives (Higgins 1994). Criticism of the ideas raised and posing of the question ‘is it possible?’ (marked with ? in Fig. 10.3) were reserved until later.

After a sufficient number of ideas had been generated, the student teachers chose the most appropriate solution by comparing the positive feedback and constructive questions that related to each idea. Typically, the final solution was a combination of several original ideas. During the ideation phase, the student teachers were encouraged to follow the OMPS method and utilize idea-generation techniques while working in groups. After selecting the final ideas, the student teachers then planned how they would build the structure or perform the process.

After generating various alternatives, evaluating them and designing and planning the product, the student teachers then created something new for their design solution process by utilizing paperboard, wood, metal and/or plastic and the appropriate tools. The teams spent approximately 12 h in the workshop, working according to their previously agreed plans. The intention was for the student teachers to be creative in their teams and modify their preliminary plans during the practical work session. Finally, each team presented their innovations to the other groups and evaluated both the innovations and the entire process, first by themselves and then with the others. The construction phase (working with the appropriate tools, using paperboard, wood, metal and other materials) was videotaped, but as interaction between the group members was based on physical action rather than verbal communication, it was not included in this study. An example of an OMPS map constructed during the creative phase is presented in Fig. 10.3.

Of the 118 student teachers participating in the course, 80% were female, and the average age of the participants was 24. According to the background information collected from the participants, 77% had little or no previous knowledge or experience of the content and methods of technology education. Less than 10% of the participating student teachers did not describe themselves as having a high level of motivation and responsibility in their work. Only about 15% of the participating student teachers thought that the course was of little significance to primary school teaching, or that the course offered little that was applicable to their work. In other words, 85–90% of the participants were satisfied with what they had learned on the course.

10.3 Empirical Research

The aim of this study was to examine student teachers’ creativity by revealing the creative process and to find out the extent to which they learn creative skills, especially those involving generating alternative ideas and self-evaluating them. In addition, we tried to evaluate the interaction between student teachers in a problem-solving process that includes several phases, from recognizing a problem to testing and evaluating it, and in which a small group of student teachers together solved a problem in the context of science and technology education. The main research questions were:

1. What are the key factors in creative problem-solving processes from the point of view of primary school student teachers?
2. Did the student teachers learn any creative skills as a result of their participation in the course?
3. What kind of interaction was found during the problem-solving process?
4. What kinds of problem-solving styles were used in the problem-solving process?

10.3.1 Research Methods

In order to evaluate the creative problem-solving processes, a questionnaire consisting of 23 items was utilized. This yielded self-evaluative data on the student teachers' success regarding the conceptualization and evaluation of ideas and on their success with creative problem solving. Of the 118 participants, 85 answered the questionnaire.

The items were formulated on the basis of theoretical ideas about the features of creative problem-solving processes. For each Likert-type item, there were five alternatives, varying from 'Strongly Disagree' (=1) to 'Strongly Agree' (=5). The questionnaire included some items about the students' background, as well as items about their motivation and general success during the teaching experiment. The items were located randomly in the questionnaire, and it was accessible on the Internet. The student teachers were asked to fill in the questionnaire after the last meeting of the creative and co-operative science and technology education course.

Exploratory factor analysis was used to reduce the large number of original variables to a smaller number of factors. Furthermore, the aim was to examine how the problem-solving process was experienced by the student teachers. The Kaiser-Meyer-Olkin Measure (KMO) was .80, which is within a very reasonable range (Norusis 1988). Bartlett's test of sphericity also supported the use of a factor analytic approach (Bartlett's test $=845.9$, $p<.00001$). Moreover, the skewness and kurtosis values were within a reasonable range and thus allowed the utilization of multivariate methods.

Although all our student teachers were asked to fill in a questionnaire, video recordings were used as an alternative data collection method. The recordings were made in the middle of the project, when student teachers were working in groups of three or four. The recordings were made from the beginning of the idea-generating process. Each recording continued until the student teachers had chosen the final alternative, which they further developed in the practical workshop. Each recording

Table 10.1 Description of the task categories in problem-solving activities and examples of typical student teachers' behaviour

Code	Description of the category	Example
+	Positive verbal or non-verbal feedback	That is ok
++	Very positive feedback	*That is very good*
0	Neutral feedback	*I do not know about that*
–	Negative feedback	*I do not like that idea*
1	Identifying the problem	*What is our problem in this project?*
1.2.	Facts related to the problem	*It must be a toy*
1.4.	Ideation of the problem	*A toy with some mechanics and electricity*
1.5.	Evaluation of the problem	*Is it just a toy or something else?*
2	Identifying the facts and the goals	*We must finish this in 10 h*
2.3.	Opinions related to the goals	*It must be nice and sweet*
2.4.	Ideation of the goals	*Is really learning something one of our goals?*
2.5.	Evaluation of the goals	*Is aesthetics really so important?*
3	Presenting the opinions	*These are just our own opinions, not facts*
3.5.	Evaluation of the opinions	*Do we really have to use the toy?*
3.8.	Development of the opinions	*We must built something that is useful*
4	Presenting the idea	*Can we build a car?*
4.2.	Facts related to the idea	*There must be lights on it*
4.3.	Opinions related to the idea	*Yes, but it must be simple enough*
4.5.	Evaluation of the idea	*It is easy to put electricity and mechanics on it*
4.8.	Development of the idea	*We can build a racing car*
5	Evaluation	*Is this really a good idea?*
5.3.	Opinions related to the evaluation	*First, we must have plenty of ideas*
6	Choosing the alternatives	*I like the idea of a racing car*
6.3.	Opinions related to the alternatives	*It is a good idea if we can make it simple enough*
6.5.	Evaluation related to the alternatives	*There are many positive things in this idea*

lasted for approximately 1 h. Consequently, we recorded a total of 3 h and 18 min of the student teachers' activities. The videos include all kinds of activities related to the idea-generating process, and the student teachers' discussions can be clearly heard on the tapes.

After the recordings had been made, a researcher viewed the videotapes twice and discussed the preliminary findings with his colleagues. After that, he transliterated all the verbal and non-verbal events on the videos. He played and replayed the videos at least four times to find out the specific meaning of the events and transcribed all natural talk between the student teachers. These notes comprised about 40 standard pages.

The categories we used for analysing the data reflected our theoretical background, while also taking into account the notes from the videos. Table 10.1 presents the main categories and subcategories along their definitions and typical examples.

10.4 Results of the Questionnaire

The questionnaire data were analysed using SPSS analytical software, utilizing principal axis factoring as the extraction method and varimax with Kaiser normalization as the rotation method. This method was used to determine how student teachers experienced the key factors in the creative problem-solving processes. The exact number of factors was determined by means of Cattell's scree test. Comprehensibility criteria were also used, and the number of factors was limited to four, since the meaning of the factors was readily comprehensible (Dunteman 1989). To determine the internal consistency of each factor, a Cronbach alpha coefficient, based on the average inter-item correlation, was determined for each factor. The Cronbach alpha coefficients varied between 0.83 and 0.88. Each factor therefore measured one quality, which allowed for a meaningful interpretation of the factors. On the other hand, no far-reaching generalizations were allowed regarding the structure or properties of the problem-solving processes. Factor analysis simply made it easier for us to describe how these 85 students experienced creative problem-solving processes during the course.

On an aggregate level, these four factors explained 57.2% of the common variance, with eigenvalues of 6.19, 2.14, 1.42 and 1.13, and percentages of total variance of 32.57%, 11.26%, 7.46% and 5.96%, respectively. A communality figure of 57.2% indicated that four factors could be used satisfactorily as predictors for all 19 variables. Moreover, the extent to which each item played a role in the interpretation of the factors was high. The eigenvalues indicate that Factor 1 covered most of the variance, accounting for roughly as much variance as the other factors combined.

Each of the four factors indicating the student teachers' perspectives on the problem-solving processes and the variables (items) that described the highest loading on each factor are presented in Table 10.2. There were three items that also had loadings of over 0.30 on factors other than their main factors, and these are discussed below. The factors were labelled on the basis of the researchers' discussion on the variables (items) loading on a factor. The mean and standard deviation (SD) of each item are also presented in Table 10.2.

Factor 1, *Success in problem-solving processes*, explained 32.5% of the total variance and included seven items. The first two items (F1I1 and F1I2) loading on this factor are connected to the problem-solving processes. Recognizing problems (F1I6) and restricting a problem (F1I7) are typically found in the initial phase of the problem-solving process. The creative atmosphere that is indicated in items F1I5 and F1I3 is necessary to establish a creative problem-solving process. Another prerequisite for successful problem solving would be knowledge about ideation techniques and ideation skills. These perspectives to problem-solving processes are indicated in items F1I3 and F1I4, which describe perspectives for ideation. However, they neither explain how student teachers succeeded in generating alternatives nor what the quality of their ideation was.

Factor 2, *Productive ideation,* consisted of six items and explained 11.3% of the variance. It indicated the students' opinions on their ideation skills. Two items

Table 10.2 Means and standard deviations (*SD*) and varimax (with Kaiser normalization rotated factor loadings for principal axis factoring) calculated from the items measuring primary school student teachers' ($n=85$) opinions about the creative process on the course

	Mean	SD	Factor loading
F1: Success in problem-solving processes			
Cronbach α for the factor = 0.84			
F1I1: I learned to work according to the principles of creative processes	3.57	.94	.905
F1I2: I learned about the nature of creative processes	3.72	.92	.851
F1I3: I believe in the principle 'it is possible to generate new alternatives'	3.55	.90	.595
F1I4: I learned ideation models	3.87	.86	.570
F1I5: I learned to generate a creative atmosphere	3.11	.95	.564
F1I6: I learned to recognize problems around me	3.30	.90	.499
F1I7: I learned to identify (set) and restrict a problem	3.65	.79	.445
F2: Productive ideation			
Cronbach α for the factor = 0.83			
F2I1: I learned to generate original ideas	3.38	1.08	.709
F2I2: I learned to generate many alternatives	3.36	.89	.707
F2I3: I learned to be in turn both intuitive and systematic	3.37	.99	.655
F2I4: I learned to develop further ideas presented by other students	3.72	.90	.578
F2I5: I learned to trust the principle, 'if we have many ideas, at least some of them will be high-quality ideas'	3.91	.85	.558
F2I6: I used my creativity	3.48	.96	.487
F3: Collaborative support and evaluation			
Cronbach α for the factor = 0.87			
F3I1: I learned to give positive feedback to other students' ideas	4.02	.77	.882
F3I2: I learned to appreciate others' ideas	4.19	.76	.845
F3I3: I learned to recognize advantages in the ideas of others	4.14	.63	.657
F3I4: I take a positive (and constructive) attitude to the ideas the other students present	3.99	.78	.646
F4: Positive attitude			
Cronbach α for the factor = 0.88			
F4I1: I was positive in creative processes	3.59	.83	.930
F4I2: I took a positive attitude to creative processes	3.63	.91	.726

(F2I1 and F2I4) relate to the originality and imaginativeness of the ideas. It is important that ideas generated during a creative process are original – otherwise the process would be routine rather than creative. It is also important that students learn to combine and develop others' ideas further. The key issue for success in creative processes is how the creative power of the group can be utilized to find new, innovative ideas. The number of ideas (F2I2, F2I5) is also very important. It is known that at the beginning of an ideation session, common and familiar ideas typically come to mind. However, if a group produces many ideas, there is more change of some of them being highly original. It is important to use creativity (F2I6) and to be in turn both intuitive and systematic (F2I3) during the process of ideation.

Factor 3, *Collaborative support and evaluation*, consisted of four items and explained 7.5% of the variance. Items F3I1 and F3I4 related to whether the students learned to express their feedback positively and constructively. The two remaining items (F3I2, F3I3) dealt with positive attitudes when evaluating ideas.

The remaining two statements loaded on Factor 4, *Positive attitude*, explained 6.0% of the variance. Item F4I1 indicates whether the students behaved positively, and the other item (F4I2) deals with positive attitude, which is one of the main features in generating an open, encouraging and innovative atmosphere.

The mean values of the two first items loading on F1 were 3.6 and 3.7. Thus, most students thought they had learned about the nature of creative processes and also how to work according to the principles of creative processes. This was expected, as these topics were emphasized during both the lecture and the workshops concerning the nature of creative processes. Much time was also spent on understanding the meaning of ideation and the evaluation of ideas. The means of the items loading on the second factor indicate that, according to the self-evaluative data, the students had learned (at least reasonably well) to generate alternatives. The means of all the items loading on the third factor indicate that the students had, in their own opinion, learned how to give positive, constructive feedback regarding other students' ideas. It is worth noting that there was much discussion on how to give constructive feedback, and this was also practised during the project. The discussion even went as far as to examine the meaning and value of such behaviour during creative processes. The student teachers were familiar, for example, with how positive feedback defines what is valuable in an idea presented by another student. Moreover, positive peer feedback was important for enhancing the self-respect and confidence of other student teachers.

10.5 Results of the Video Recordings

In this study, three groups of three or four members were selected to be videotaped. The videotapes were later analysed with a focus on the steps in the creative problem-solving process and the styles of problem-solving process presented earlier in Fig. 10.1.

After defining the categories, all videotaped activities were analysed. In total, there were 570 spoken episodes with an average duration of 6.3 s during one 60-min videotaped period. In addition, 242 episodes of verbal or non-verbal feedback were registered. Most of the feedback given to other students was positive (160 episodes/67%). Neutral feedback was given in 76 episodes (31%), and negative feedback in only six episodes (2%). So the idea of non-judgemental positive feedback and the acceptance of all ideas, even those which were absurd or impractical, were realized, and there seemed to be room for free ideation.

All the episodes in the entire 60-min process were classified according to the stages of the problem-solving process (identifying the problem, identifying the facts, presenting opinions, presenting ideas, evaluation of the ideas and choosing the alternatives). These stages were explained in more detail, with examples of student teachers' typical behaviour, in Table 10.1. At the beginning of the process, most of the facts (certain rules and restrictions that must be included in the course) and goals were discussed during the first 20 min. In addition, the problem was identified, and most of the opinions were presented in the first 20-min period. However, the most typical problem-solving activity was presenting ideas, which accounted for 325 episodes (57% of all episodes). In more detail, this stage consisted of presenting an idea (98 episodes), facts related to the idea (9 episodes), opinions related to the idea (27 episodes) and development of the idea (191 episodes). Finally, a second typical problem-solving activity among student teachers was evaluation of the ideas, which accounted for 140 episodes (25% of all episodes).

In the next phase, we tried to discover the kinds of problem-solving styles that were used in each step of the problem-solving process. In this study, we focused on the six main categories of the creative process and on the styles of problem solving derived from Strzalecki's (2000) model, which was described earlier in this article. These problem-solving steps are also included in the OMPS method and are quite similar to the stages of the problem-solving process. The student teachers used many different problem-solving styles, but at the beginning, most of the styles were quite conservative and the ideas were not especially innovative. At this stage, most popular problem-solving styles were rationalism, conservatism and an active approach to problem.

The real idea-generating process started after the first 20 min and gathered pace throughout the 60-min period. Fourteen episodes (14%) where ideas were presented occurred in the first 20-min period. However, most of the ideas (58 episodes/59% of all ideas) were presented in the second 20-min period, with 26 such episodes (27%) occurring in the last 20-min period. In this phase, the problem-solving styles were much more open and flexible. The most popular styles were independent thinking, openness, flexibility and intuitive thinking. Problem-solving styles do not guarantee the quality of the ideas produced, but in this case, it was evident that the originality of the ideas and the level of imagination was not merely routine. The frequencies of each category are presented in Table 10.3.

Only 26 occasions (13%) involving the further development of ideas occurred in the first 20 min, while 70 occasions (37% of all development episodes) appeared in the second and as many as 95 occasions (50%) in the last 20-min period. It seems that if we want to get plenty of ideas, the idea-generating process must last at least 30 min. If the idea-generating process is short, the ideas and styles of problem solving are usually quite traditional and stereotyped and do not fulfil the goals of generating innovative processes in problem solving. The best way to get new, innovative ideas was to have as many ideas as possible for the student teachers to choose from and further develop.

10.6 Discussion

There have been numerous models available for curriculum changes in science and technology education and for introducing creative problem-solving processes for quite some time, both in the technology education literature and in school textbooks

Table 10.3 The frequency of problem-solving styles at each step of the problem-solving process. The categories are based on Strzalecki's (2000) model, which was presented earlier

Styles of solving problems (number of episodes)	Identifying the problem	Identifying the facts	Presenting opinions	Presenting ideas	Evaluation of the idea	Choosing the alternatives
	Frequencies	Frequencies	Frequencies	Frequencies	Frequencies	Frequencies
1. Active and systems approach to problems (26)	3	6	5	10	2	
2. Responsibility (42)	2	5	2	6	27	
3. Transgression (12)	2		3	5	2	
4. Objectivism (44)	1	3		15	25	
5. Analogy seeking (19)				19		
6. Modular thinking (21)		3	2	7	9	
7. Intuitive thinking (83)			4	75	4	
8. Conservatism (41)	6	8	12	9	6	
9. Rationalism (73)	7	5	10	36	14	1
10. Reductive thinking (42)				6	34	2
11. Openness (63)			5	52	5	1
12. Flexibility (104)		1	6	85	12	
Total (570)	**21**	**31**	**49**	**325**	**140**	**4**

(Johnsey 1995). However, in spite of some progress, the legacy of behaviourist, teacher-centred, whole-class teaching methodologies, with the teacher as expert and the student as the passive recipient of knowledge, repeatedly appears as the dominant orthodoxy in education to this day (Dakers 2005). An important function of science and technology education is to provide the opportunity to transcend from routine activities and low-level thinking, so that students can find new, innovative ideas and approaches to problem solving. This can be achieved, for example, by utilizing group dynamics or special creative methods (e.g. Smith 1998).

The present study shows that creativity cannot be taught directly, but it can be learned effectively through co-operative creative problem-solving processes. Based on the means and standard deviations of the self-evaluative data on creative process skills, we can assume that the Overall Mapping of a Problem Situation (OMPS) method helped our student teachers to understand the nature of creative processes and, in particular, that there are different phases involved in each of these processes. Factor 1 vindicates our assumption that most student teachers learned about the nature of creative processes and also how to work according to the principles of these processes. This result was to be expected as these topics were emphasized during both the lecture and the workshops.

Factors 2 and 3 indicate that the student teachers believed they had succeeded in generating alternatives and, in particular, had learned to evaluate and appreciate others' ideas. This means that the students felt they had learned to give positive feedback regarding other students' ideas, recognize the advantages of those ideas and even develop them further. We assume that a structured method, where each idea had to be supported by a presentation with at least three reasons for its adoption, was necessary for successful problem solving. Such evaluation creates a positive, non-judgemental atmosphere for creativity, and it helps participants to behave positively, as indicated in Factor 4.

The interaction data confirm that our student teachers learned to give positive feedback on other students' ideas, recognize the advantages of those ideas, and even develop them further. Our findings also suggest that the students worked co-operatively. The students shared their cognitive resources, talked, recognized facts, planned and evaluated with the aim of solving problems and producing a single outcome through dialogue and action.

The idea of the whole problem-solving process was to generate a large number of new, innovative ideas. The process started slowly, and in the beginning, only small number of ideas was produced. What is more, most of the ideas were quite conservative and not especially innovative. After the first 20 min, the idea-generating process accelerated all the time throughout the 60-min period. In addition, the problem-solving styles were much more open and flexible. The most popular styles in the last 20 min were independent thinking, openness, flexibility and intuitive thinking.

It seems that we must be patient at the beginning of the problem-solving process and try to give plenty of positive feedback, in order to build an open, supportive and permissive atmosphere. After half an hour, the idea-generating process will suddenly accelerate, and if we want to get large number of ideas, the process must last at least 30 min. In the end, the best way to get new and innovative ideas is to have plenty of ideas to choose from.

Nevertheless, some student teachers felt that they had not learnt enough about the generation of many original, new alternatives. Such skills are important when extremely new alternatives are required (Amabile 1996). From the point of view of further similar projects, it is important to note that more efficient guidance in generating alternatives is needed. Furthermore, students should receive a thorough introduction to creative problem solving in general (Williams and Williams 1997). Such training would be beneficial because many students became anxious when there was no formula or direct guidance to help them with their work. Although the students attended 2 h of lectures and demonstrations about creative problem solving and became familiar with the theme through websites, the learning process was not particularly active, as the lectures were given using traditional methods. As the student teachers were directly taught very little, they did not have sufficient planning and ideation skills. In fact, though manuals and handbooks were available all the time, the difficulty was that the student teachers did not have enough time to learn new knowledge during the activity stage.

It is easy to talk about creative problem solving in general, but organizing co-operative problem-solving situations and learning activities is not as easy as it seems (Murdock 2003), and it is even more difficult to measure and define this process with reliable concepts (Kaufman 2003). It will be interesting to see how our findings can be put into practice.

References

Amabile, T. M. (1996). *Creativity in context* (pp. 88–89). Boulder: Westview Press.

Dakers, J. (2005). The Hegemonic behaviorist cycle. *International Journal of Technology and Design Education, 15*(2), 111–126.

Dooley, C. (1997). Problem-centred learning experiences: Exploring past, present and future perspectives. *Roeper Review, 19*(4), 192–196.

Dunteman, G. H. (1989). *Principal components analysis: Quantitative applications in the social sciences series, No. 69*. Thousand Oaks: Sage.

Fisher, R. (1990). *Teaching children to think*. Oxford: Basil Blackwell, Ltd.

Grabinger, R. S. (1996). Rich environments for active learning. In R. Jonassen (Ed.), *Handbook of research for educational communications and technology. A project of the association for educational communications and technology (AECT)* (pp. 665–691). London: Prentice Hall International.

Higgins, J. M. (1994). *Creative problem solving techniques: The handbook of new ideas for business*. Winter Park: New Management Publishing Company, Inc.

Hill, J. R. (1999). Teaching technology: Implementing a problem-centered, activity-based approach. *Journal of Research on Computing in Education, 31*(3), 261–280.

Johnsey, R. (1995). The design process: Does it exist? A critical review of published models for the design process in England and Wales. *International Journal of Technology and Design Education, 5*, 199–217.

Kaufman, G. (2003). What to measure? A new look at the concept of creativity. *Scandinavian Journal of Educational Research, 47*(3), 235–252.

Lavonen, J. M., & Meisalo, V. P. (2001). *Luovan ongelmanratkaisun työtavat* [Models of teaching in creative problem solving]. Retrieved October 2, 2002, from http://www.malux.edu.helsinki.fi/kirjasto/lor/

Murdock, M. (2003). The effects of teaching programmes intended to stimulate creativity: A disciplinary view. *Scandinavian Journal of Educational Research, 47*(3), 339–357.

Norusis, M. J. (1988). *SPSS/PC advanced statistics (V 2.0)*. Chigago: SPSS.

Parker, G. M. (1991). *Team players and teamwork: The competitive business strategy*. San Francisco: Jossey–Bass.

Sellwood, P. A. (1991). The investigative learning process. *Journal of Design & Technology Teaching, 24*(1), 4–12.

Smith, G. (1998). Idea generation techniques: A formulary of active ingredients. *Journal of Creative Behaviour, 32*(2), 107–133.

Strzalecki, A. (2000). Creativity and design. General model and its verification. *Technological Forecasting and Social Change, 64*, 241–260.

Williams, A., & Williams, J. (1997). Problem based learning: An appropriate methodology for technology education. *Research in Science & Technological Education, 15*(1), 91–103.

Chapter 11
Increasing Accessibility to Science in Early Childhood Teacher Education Through Collaboration Between Teacher Educators and Science/Engineering Academics

Christine Howitt, Elaine Blake, Martina Calais, Yvonne Carnellor, Sandra Frid, Simon W. Lewis, Mauro Mocerino, Lesley Parker, Len Sparrow, Jo Ward, and Marjan G. Zadnik

11.1 Introduction

Various reports have identified urgent needs for science education in Australia, in particular, in relation to maintaining and increasing capability to teach science at all levels of schooling (e.g. Australian Academy of Technological Sciences and Engineering 2002; Goodrum et al. 2001; Tytler 2007). The most recent reports at both the national and state levels have recommended the development of comprehensive 'action plans'. For example, the Commonwealth sponsored the initial phase of production of a *National Action Plan for Australian School Science Education 2008–2012* (Goodrum and Rennie 2007). Many of these reports highlight a 'crisis' in science education, in terms of students', teachers' and national needs. Briefly, they provided convincing evidence that students are not enrolling in science courses or science education courses in sufficient numbers; appropriately trained teachers of

---

C. Howitt (✉)
Graduate School of Education, The University of Western Australia, Perth, WA, Australia
e-mail: christine.howitt@uwa.edu.au

E. Blake • L. Parker
Science and Mathematics Education Centre, Curtin University, Perth, WA, Australia

M. Calais
School of Engineering and Energy, Murdoch University, Perth, WA, Australia

Y. Carnellor • S. Frid • L. Sparrow
School of Education, Curtin University, Perth, WA, Australia

S.W. Lewis • M. Mocerino
Department of Chemistry, Curtin University, Perth, WA, Australia

J. Ward
School of Science, Curtin University, Perth, WA, Australia

M.G. Zadnik
Department of Imaging and Applied Physics, Curtin University, Perth, WA, Australia

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_11,

science are in short supply; the science-related background of teachers, particularly those at primary and early childhood levels, is inadequate especially in an increasingly scientific and technological society; and the critical shortage of people with science, technology, engineering and mathematics (STEM) knowledge, skills and/or appreciation continues to be a national concern, especially in innovation and economic terms.

Over the past decade, a number of initiatives have attempted to address the student-related dimensions of this problem, particularly increasing engagement in STEM at the upper primary and secondary school levels. Examples of these include the Australian Academy of Science ‘Primary Connections’ programme, the Collaborative Australian Secondary Science Programme (CASSP), the Creativity in Science and Technology (CREST) programme, the Science Education Assessment Resources (SEAR) programme, the Australian Science Teachers’ Association Science Awareness Raising Model and the recent Scientists in Schools (SiS) programme. However, few of the initiatives to date have focused specifically on the needs of pre-service teachers, and even fewer have addressed the needs of early childhood pre-service teachers.

This chapter reports on the outcomes of a project that took a highly collaborative and cross-discipline approach among teacher educators, science/engineering academics and early childhood pre-service teachers to encourage the latter to teach more science, with greater confidence, in the classroom. This collaborative approach involved both the development and delivery of science modules within a science methods course. For the purposes of this research, early childhood was defined as children between the ages of 3 and 8 years. The first part of this chapter describes the literature in relation to three relevant areas of research. First, the characteristics of early childhood pre-service teachers are described in relation to science. Second, various approaches used to improve pre-service teachers’ confidence and competence to teach science are discussed. Third, an overview of collaboration between scientists and teachers is presented. In the remainder of the chapter, the project design and findings are discussed.

11.1.1 Characteristics of Early Childhood Pre-service Teachers: A Focus on Science

Based upon their diverse backgrounds and individual experiences, pre-service early childhood teachers bring a unique set of characteristics with them when they are learning about science and how to teach science. Pre-service teachers bring many strengths, and thus potential resources, into their teaching and learning. Such strengths include respect for children’s intellect, curiosity and questioning; celebration of children’s wonder of the natural world; excitement associated with children’s exploration and discovery of the natural world; and a willingness to develop instruction based upon children’s thinking that embraces open-ended enquiry (Howes 2002). Fleer (2006) also considered pre-service teachers' informal science knowledge gained through interests and hobbies to be a further strength. Howes (2002) suggested that working with their strengths provides pre-service teachers a greater opportunity to connect with science in a manner that is comfortable to them and subsequently believe in themselves as teachers of science.

In contrast, many pre-service early childhood teachers see themselves as 'non-science' people trying to become science students at university (Mulholland and Wallace 2003). They consider themselves to have poor science knowledge, which tends to be limited in quantity, narrow in perspective and characterized by a lack of understanding of the nature of science (Appleton 2006). Pre-service early childhood teachers often lack previous science experiences or have experienced negative science experiences, mostly in secondary school, resulting in them perceiving science as only for the intellectually gifted or having a masculine image (Mulholland and Wallace 1996). They tend to have poor attitudes and beliefs about science and their capacity to be effective teachers of science (Watters and Ginns 2000), this leading to an avoidance of teaching science (Harlen and Holroyd 1997). Finally, pre-service early childhood teachers tend to have well-developed but often simplistic views of the science teaching and learning process, leading to inappropriate science teaching strategies and learning experiences (Appleton 2006). These factors contribute to the lack of confidence that pre-service early childhood teachers have towards science and the teaching of science.

11.1.2 Improving Pre-service Teachers' Knowledge and Confidence Towards Science

A substantial body of research exists on how best to improve pre-service primary teachers' science knowledge of and confidence towards science. The majority of this research has been directed at improving science content knowledge and science methods courses with the aim of improving the confidence of the pre-service teachers (Appleton 2003). The influence of the science teacher educator in improving the confidence of pre-service primary teachers by creating an effective science learning environment also has been examined to a lesser degree (Rice and Roychoudhury 2003). In general, results indicate that learning environments need to be positive and supportive to minimize anxiety and encourage freedom to experiment and verbalize opinions (Huinker and Madison 1997). Courses should include a variety of authentic teaching methods that concentrate on student-centred learning experiences and make connections with prior knowledge. Pre-service teachers should be supported by consistent feedback to allow for the development of science understanding and pedagogy and improved beliefs and attitudes about science and themselves as teachers of science (Huinker and Madison 1997). These results suggest that the science methods course should include a wide range of factors to improve pre-service teachers' knowledge and confidence towards science.

Various researchers have advocated a pedagogical content knowledge (PCK) approach in teacher education courses, through successful experiences at the pre-service level, as a means of increasing primary teachers' confidence towards science (Appleton 2003, 2006; Rice and Roychoudhury 2003). PCK is one of many different forms of knowledge that teachers draw upon, which includes subject matter knowledge (or content knowledge) and general pedagogical knowledge (Shulman 1986). PCK is considered different to the latter two forms of knowledge, as it is a form of knowledge in action (Zeidler 2002). Appleton (2006) defined science PCK as 'the knowledge a teacher uses to construct and implement a science learning experience or series of science learning experiences' (p. 35). Science PCK is a dynamic form of knowing as it has close links with a teacher's science content knowledge and is developed through the teacher's own science experiences and science teaching practices (Appleton 2003, 2006).

While science PCK is necessary in order to teach science, it is not automatically generated from science content and other forms of teacher knowledge (Appleton 2006). As a means of developing science PCK, Appleton (2003) suggested pre-service teachers develop a series of activities organized in a pedagogical sequence designed to facilitate pre-service teachers' conceptual understanding. They suggested that such units would include learning experiences, key teaching strategies and explanatory science notes. Appleton (2003) also suggested that science content would be most meaningful to pre-service teachers when it is dealt within a pedagogical context, which includes a focus on student preconceptions and how to deal with these while teaching. These findings suggest that participating in authentic science experiences where both content and pedagogy is made explicit provides an opportunity to increase pre-service teachers' PCK.

11.1.3 Collaboration Between Scientists and Teachers

Improving science education by having scientists work with teachers is not a new idea (Drayton and Falk 2006). The proposition is that scientists working with *K*-12 teachers assist in making that science more meaningful, with the teachers in turn making science more meaningful for their students. Scientists, possessing science content knowledge, process knowledge and the structure of their field of knowledge, are considered an untapped resource of the practical application of science (Drayton and Falk 2006). There are many successful examples of apprenticeship programmes involving scientists in classroom enquiry, fieldwork or laboratory activities (Bell et al. 2003; Crawford 2009; Drayton and Falk 2006; Howitt et al. 2009). Similarly, working at the higher education level, Martin-Dunlop and Hodum (2009) reported on the successful collaboration between a scientist and a science teacher educator to assist pre-service primary teachers' develop their science content knowledge, attitudes towards science and understanding of the nature of science.

11.1.4 Research Questions

The following research questions will be addressed in this chapter.

1. How does a collaborative approach between teacher educators and science/engineering academics to developing and delivering science curricula assist early childhood pre-service teachers' confidence to teach science and science content knowledge?
2. How did the pre-service teachers translate this new knowledge into the early childhood classroom?

11.2 Methodology

The following sections describe the action research approach, project team, development of the science modules, implementation of the modules into the science methods course, evaluation of the pre-service teachers' confidence and science content knowledge and teaching science in the early childhood classroom.

11.2.1 Action Research as Participatory Curriculum Development

Acknowledging that action research is a process of enquiry incorporating multiple stakeholders (Stringer 2008), a participatory curriculum development approach was utilized throughout the research. Participatory curriculum development encourages diverse stakeholders in participatory procedures to create curricula that incorporate their needs, perspectives and interests into effective programmes of learning (Stringer 2008). Through this approach, science modules were developed, trialled, evaluated and redeveloped in an ongoing manner by a range of participants.

11.2.2 Project Team

The project team consisted of ten members from two Western Australian universities, five each from teacher education and science/engineering. One member from each discipline was also involved at a strategic leadership level. Each scientist/engineer was individually invited to be part of the project, based on recognition of their exemplary undergraduate teaching and learning record, ability to work in a group and their perceived ability to interact in a positive and supportive manner with early childhood pre-service teachers.

11.2.3 Development of Modules

Four science modules were developed through collaboration between the teacher educators and the science/engineer academics, covering the themes of day and night, forensic science, the science of cleanliness and solar energy. The information presented within each module aimed to provide a broad range of possible ideas and activities that could be used within an early childhood classroom. The modules were designed to be adaptive and flexible, rather than set teaching programmes, so that teachers could use the materials in a manner that suited their particular context.

A philosophy and template were developed from which to construct the modules (Howitt and Blake 2010). Embracing best practice early childhood education, the philosophy was based upon five principles: acknowledgement of the place of young children as natural scientists, active involvement of children in their own learning through play and guided enquiry, recognition of the place of a sociocultural context within children's learning, emphasis on an integrated approach to children's learning experiences and the use of a variety of methods for children to demonstrate their understanding and learning. Each module was developed around a template that consisted of an overview; a range of introductory core activities that established a suitable context; focus questions relating to these core activities; a range of follow-up activities, including concluding activities; possible resources; suggested forms of diagnostic, formative and summative assessment; questions and answers (covering science content); and suggestions for integration across the different curriculum learning areas.

11.2.4 Implementing the Modules into the Science Methods Course

The developed modules were implemented into a 12-week science methods course during the third year of a 4-year Bachelor of Education (Early Childhood Education) degree during semester 2, 2008. There were 38 pre-service early childhood teachers within this course. The weekly 3-h workshops delivered during the course aimed to develop the pre-service teachers' science PCK through active scientific enquiry. The first author was the principle lecturer for the workshops. Each workshop consisted of a mini-lecture (30–40 min) that presented the science curriculum and each science conceptual area. This was followed by a range of hands-on activities that were specific to one science conceptual area. A sequential range of science activities were either presented in each workshop or provided in a detailed handout relating to that workshop. The science learning experiences within the workshops were characterized by active participation, placement with an authentic early childhood context, discussion of children's views of science and learning within a social constructivist environment.

Each scientist/engineer took an active role in the workshop where the module they had assisted in developing was delivered. A team teaching approach was modelled between the principle lecturer and scientist/engineer. Through discussion between the principle lecturer and the scientist/engineer, selected activities from the developed modules were chosen to be presented in the workshops.

11.2.5 Evaluating Pre-service Teachers' Confidence and Science Content Knowledge

Data were collected from a range of methods: formal questionnaires, open-ended questions, posters and interviews.

As a general measure of the pre-service teachers' science teaching ability, they were asked four questions in week 2 and again in week 12 of the science methods course. The four questions related to their perceived interest in teaching science, background knowledge for teaching science, confidence in teaching science and enthusiasm for teaching science. These questions had a five-point range of responses from 'Not Interested'/'Limited'/'Not Very Confident'/'Rarely' to 'Interested'/'Extensive'/'Confident'/'Always'. The responses were analysed by descriptive statistics, summarizing pre- and post-percentage responses and presenting these as a comparison.

Pre-service teachers' confidence to teach science was measured with a modified Personal Science Teaching Efficacy (PSTE) scale from the Science Teaching Efficacy Belief Instrument (STEBI-B). PSTE is defined as the belief in one's ability to teach science effectively (Huinker and Madison 1997). STEBI-B has been found to be a valid and reliable instrument for measuring science teaching efficacy in pre-service teachers (Enochs and Riggs 1990; Ginns et al. 1995) and has been used in a wide range of studies (Cantrell et al. 2003; Palmer 2006; Watters and Ginns 2000).

PSTE pre- and post-tests were administered in weeks 2 and 12, respectively. The PSTE was modified by changing all 13 questions to the affirmative, simplifying the questions and allowing a five-point range of responses other than the standard responses of 'Strongly Disagree', 'Disagree', 'Neutral', 'Agree' and 'Strongly Agree'. Depending on the question, responses to the modified PSTE ranged from 'Rarely'/'Limited'/'Different' to 'Always'/'Extensive'/'Easy'. For example, the question 'even when I try hard, I will not teach science as well as I will most subjects' was changed to 'compared with other subjects I will find it easy to teach science' with responses ranging from 'Rarely' to 'Always'. Statistical differences between the pre- and post-test PSTE were obtained with the use of a paired *t*-test.

At the end of the semester the pre-service, teachers were also given an open-ended questionnaire relating to confidence in science teaching and science knowledge. If they thought their confidence to teach science, or knowledge and understanding of science, had changed as a consequence of the science methods course, the pre-service teachers were asked to briefly explain how and why these had changed. Responses to these two questions were analysed, and common themes identified. The percentage of pre-service teachers who commented on each common theme was then calculated. Comments from the pre-service teachers relating to each theme were used to highlight certain responses.

To further measure the pre-service teachers' learning over the semester, as part of formal assessment, they were asked to produce a poster that summarized what content they had learned in each of the four workshops where a science/engineering academic had been present. Responses on the poster were analysed, and common themes identified. The percentage of pre-service teachers who commented on each theme was then calculated. Comments from the pre-service teachers relating to each theme were used to highlight certain responses.

11.2.6 Teaching Science in the Early Childhood Classroom

At the end of the 12-week science methods course, the pre-service teachers participated in a three-week teaching practice with either 4-year-old or 5-year-old children. The pre-service teachers were encouraged to use the modules to assist them to teach science during this time. However, this could not be mandated as the pre-service teachers were required to follow their cooperating teacher's advice. At the end of the teaching practice, the pre-service teachers were asked to complete a simple open-ended questionnaire on what science they taught in the classroom and how they applied their learning from the modules and the science methods course within the classroom. This was supported with interviews of three purposively selected pre-service teachers to provide more detail on how they had incorporated the modules within their planning and teaching.

11.3 Findings

The findings have been organized around the pre-service teachers' perceived science teaching ability, confidence to teach science, science content knowledge and teaching science in the early childhood classroom.

11.3.1 Pre-service Teachers' Perceived Science Teaching Ability

Table 11.1 presents the percentage response to the four questions relating to the pre-service teachers' perceived science teaching ability. For the pre-test, the pre-service teachers tended to rank themselves average/above average for their interest in teaching science and enthusiasm for teaching science, while below average/average for their own background knowledge for teaching science and confidence in teaching science. Across the science methods course, the pre-service teachers believed they had increased in all four areas, with this increase tending to reflect a whole unit increase across the five-point response scale.

Table 11.1 Pre-service teachers' perceived science teaching ability, comparing pre-test ($n=28$) and post-test ($n=32$) percentage responses

1. My own interest in teaching science is best described as	Not interested			Interested	
Pre-test	0	11	39	43	7
Post-test	0	0	22	34	44
2. My own background knowledge for teaching science is best described as	Limited			Extensive	
Pre-test	18	28	50	4	0
Post-test	3	9	31	54	3
3. My confidence in teaching science is	Not very confident			Confident	
Pre-test	4	39	50	7	0
Post-test	0	3	16	62	19
4. I am enthusiastic about teaching science	Rarely			Always	
Pre-test	0	4	28	50	18
Post-test	0	0	12	44	44

Table 11.2 Summary of pre-service teachers' reasons for increased confidence to teach science ($n=38$)

Category of reason	Percentage
How to teach science to young children	82
Science activities/resources/ideas	58
Science content knowledge	50
New views of science	10

11.3.2 Pre-service Teachers' Confidence to Teach Science

Pre-service teachers' confidence to teach science increased significantly over the science methods course. Mean total values (across the 13 items in the scale) for PSTE increased from 39.0 to 49.4 ($t=7.21$, $p<0.001$, $n=26$). As minimum and maximum values of PSTE range from 13 to 65, this equates to almost one whole unit increase across a five-point scale. The pre-service teachers tended to rank themselves as 'average' at the beginning of the science methods course, yet by the end had ranked themselves as 'above average'. These values are similar to those reported in the literature. The following authors found significant increases ($p<0.01$) in PSTE across their science methods course: Cantrell et al. (2003) from 46.3 to 53.6, Palmer (2006) from 42.0 to 53.0 and Watters and Ginns (2000) from 44.8 to 49.2. The modified PSTE scale had a high reliability (Cronbach alpha coefficient of 0.93), indicating the 13 questions were measuring the same construct.

Table 11.2 presents a summary of the reasons from the open-ended questionnaire (OEQ) the pre-service teachers believed they had increased confidence to teach science. Most responses from the pre-service teachers included more than one of the identified categories. Relevant comments from the pre-service teachers (PST) are presented to support these findings.

The majority of pre-service teachers (82%) believed that being shown how to teach science to young children was the main reason for their increased confidence. Being shown how to teach science included the use of engaging hands-on learning, letting children explore, integration across the curriculum, use of cooperative learning experiences and the importance of determining children's prior knowledge.

> Being provided with so many ideas to support science teaching, particularly in relation to where to start with very young children, and what sequence should be followed. I also have a better understanding of each of the science areas. [PST17_2008_OEQ_Q1]

Over half (58%) of the pre-service teachers identified the science activities, resources and ideas presented in the workshop as assisting their confidence to teach science.

> I have learnt so much within this unit and because of this my confidence has grown hugely. By carrying out investigations for ourselves each week, I was able to see how easy and fun science is and can therefore be taught. Everything that we have been taught can be used in the classroom and it is very exciting! I can't wait to teach science, and I used to not enjoy science through school. [PST6_2008_OEQ_Q1]

Fifty percent of the pre-service teachers mentioned science content knowledge as the reason for their increased confidence to teach science.

> I believe that my confidence has improved because I now have a stronger understanding of scientific concepts and explanations, and I know how to present them to my students. By making science activities more hands on and active, I am confident that children will be eager and willing to participate. [PST1_2008_OEQ_Q1]

A small number (10%) of the pre-service teachers mentioned the new views of science that they now had as a consequence of the science methods course as the reason for their increased confidence to teach science.

> Before I saw science as the science I learnt in high school and I knew I didn't understand it so I couldn't teach it. Now I know science can be adapted to everything and it can be done in a fun way. [PST26_2008_OEQ_Q1]

These results show that the pre-service teachers have not only increased their pedagogy, knowledge of activities that work and science content knowledge, but they have also increased the science PCK. Being shown what science to teach, how to teach that science and how to explain it to young children has not only resulted in increased confidence to teach science but an eagerness to move into the classroom and share science with the children.

11.3.3 Pre-service Teachers' Science Content Knowledge

Table 11.3 presents a summary of the reasons from the open-ended questionnaire the pre-service teachers believed they had increased science content knowledge. Most responses from the pre-service teachers included more than one of the identified categories. Almost two-thirds of the pre-service teachers (63%) believed the active participation within the workshops contributed to their increased science

Table 11.3 Summary of pre-service teachers' reasons for increased science content knowledge ($n=38$)

Category of response	Percentage
The active participation within the workshops	63
Having science/engineering academics in the workshops	45
The modules	34
Doing the assignments in the course	13

knowledge. Additionally, 45% of the pre-service teachers believed having a science/engineering academic in the workshop assisted, while a further 34% commented on the use of the developed modules. Most responses from the pre-service teachers included comments that related to two or three of the identified categories, as illustrated below.

> I have gained a far better understanding about a wide range of ideas in the field of science through this unit, due to the hands-on activities along with discussion about the activities and investigations. [PST11_2008_OEQ_Q2]
>
> By the scientists coming in especially the first workshop [astronomy] it has cleared up a great deal of misconceptions I had about space. By me learning the scientific ideas I now feel more confident in teaching it to children. [PST3_2008_OEQ_Q2]
>
> There were many aspects of science that I did not fully understand before I started this unit. The modules, however, increased my knowledge and made me think about my misconceptions. I now also know that science is all around us and know what to teach and how to teach it. [PST9_2008_OEQ_Q2]

To determine the exact nature of the pre-service teachers' learning over the science methods course, their posters were analysed for content learnt. Table 11.4 presents a summary of the major categories of response (greater than 15%) from each of the four workshops where a science/engineering academic presented. In responding to what content they learnt, Table 11.4 shows that the pre-service teachers did not restrict their comments to just science content knowledge, but also to various pedagogical strategies, and learning how to apply a certain topic at the early childhood level. This type of response was present in all four workshops.

Reflecting on the astronomy workshop, 61% of the pre-service teachers stated they had increased science content knowledge relating to the phases of the moon, seasons of the year or day and night, while 47% stated they had become more aware of their own astronomy alternative conceptions. A large percentage (45%) of the pre-service teachers stated they had a 'better understanding' of the science behind the astronomy concepts as a consequence of the workshop. Further, 16% of the pre-service teachers mentioned they had learned about the place of alternative conceptions in the teaching and learning process.

> Grappling with the concept of the 'phases of the moon' stood out in this workshop. My knowledge of this concept is rarely challenged or even discussed. Having to tell the class how these phases work was both humiliating and immensely valuable. [The scientist] noticed my struggle and provided me with his 'scientific' understanding of how these phases operate. I was then able to ask questions, clarify, demonstrate and make mistakes in a 'safe' environment until I felt comfortable with my basic conceptual knowledge. … [I experienced] the value of having a 'real' scientist present. [PST26_2008_POSTER]

Table 11.4 Summary of content the pre-service teachers learnt from each workshop in which a scientist/engineer participated ($n = 38$)

Topic	Category of response	Percentage
Astronomy	Specific facts relating to phases of the Moon, seasons of the year, shadows or day and night	61
	Awareness of own alternative conceptions	47
	‘I have a better understanding now’	45
	The place of alternative conceptions in teaching and learning	16
Forensic science	Every contact leaves a trace	55
	Uniqueness of fingerprints	47
	Misconceptions of forensic science in the media	37
	Early childhood application	37
	Procedure for taking fingerprints	29
Cleanliness	How soap works	74
	What soap and water molecules look like	34
	Using a literacy book to teach science	32
	3D mind maps	29
	Procedure for making a solar cooker	47
Solar energy	Principles of solar cooking	37
	Definition of sustainability	32
	The Sun as a source of energy	26
	Early childhood application	16
	Difference between conduction, convection and radiation	16

Reflecting on the forensic science workshop, the pre-service teachers commented on the principles of forensic science, the uniqueness of fingerprints, the correct procedure for taking fingerprints and alternative conceptions of forensic science presented in the media. Further, the pre-service teachers noted they had learned how to use the theme of forensic science in the early childhood setting, something they had previously thought impossible.

> The workshop really changed my thoughts about teaching early childhood students about forensics. Before I attended this session, I never would have even thought about bringing forensics into the classroom because when I hear forensics I just think about murders. I love the forensic bear hunt idea. It is very appropriate for young children and would help them learn in a very engaging way. This was significant to me as it challenged my ideas about forensics and bringing it into the classroom. [PST1_2008_POSTER]

In the cleanliness workshop, the pre-service teachers learnt about the process of how soap works and becoming more aware of the chemical structure of soap and water molecules. The pre-service teachers also believed they developed pedagogical content, commenting they had learned how to teach science through a literacy book and how to use 3D mind maps (Howitt 2009).

> [The] workshop allowed us to explore the extremely relevant science topics to early childhood education – cleanliness and hygiene. The concepts were integrated within the theme ‘Mrs Wishy Washy’ demonstrating to pre-service teachers the way in which scientific understandings can be made both engaging and meaningful through a literature context. [PST10_2008_POSTER]

Reflecting on the solar energy workshop, the pre-service teachers commented on a range of science concepts they had learned, including the principles of solar cooking; definition of sustainability; the Sun as a form of energy; and the difference between conduction, convection and radiation. They also commented on learning how to make a solar cooker. The use of solar energy as a theme in the early childhood setting was also mentioned.

> [I learned] the Sun is a free, natural source of energy. Knowledge of how to make use of the Sun's energy is becoming increasingly important for future generations due to our rapid consumption of fossil fuels. We can easily turn energy from the Sun into heat for cooking. We can use this knowledge in our classrooms where children utilize available materials to make their own solar cooker. [PST15_2008_POSTER]

Increased science knowledge is not simply a consequence of being presented with more scientific information. These results illustrate the interplay between learning through doing, while also having 'experts' to answer questions and the provision of materials (the modules) to obtain more information. This is further reflected in the pre-service teachers' responses to what content they learnt in the workshops where a science/engineering academic was present. Their responses were not solely restricted to science content knowledge but included science pedagogy and how to adapt science ideas for the early childhood classroom.

11.3.4 Teaching Science in the Early Childhood Classroom

Thirty-two of the pre-service teachers went on teaching practice. Of these, 28 (94%) stated they taught some science. Seventeen of these 28 pre-service teachers (61%) indicated they had used the modules to plan their science lessons: nine used the cleanliness module, five used the forensic science module, two used the day and night module and one used the solar energy module. Over half of these 17 pre-service teachers commented they adapted the ideas presented in the modules to their specific context. Comments on how the pre-service teachers applied what they had learned during the science methods course included the place of engagement and exploration, hands-on learning and multi-sensory activities, questioning, obtaining prior knowledge, small group work and using shared knowledge and ideas.

In planning their lessons, the pre-service teachers used the modules in various ways. Some relied almost entirely upon the modules, while others refereed to specific sections of the modules depending on the context of the learning.

> I chose aspects of the [forensic science] module and altered the activities to be age appropriate. The children … were engaged, motivated and immensely excited about the activities. Transferring the knowledge I learnt about forensic science and how to teach it to children proved effective. [PST1_2008_INTERVIEW]
>
> The cleanliness module really assisted my planning. I was able to base all my lessons around the module with ease. The children enjoyed the program. The module was easy to modify for this [4-year old] level. [PST2_2008_INTERVIEW]
>
> I incorporated several ideas from the cleanliness module. One of the most interesting experiences I had with the children was when I introduced them to the two mud activities

> [chocolate mousse and wet clay ideas from the module]. I [also] provided mud made from cornflour, water and cocoa [an idea not included in the module]. The children absolutely loved these activities as they had the opportunity to explore the materials,… discover science for themselves, and most of all, the experience was fun! [PST3_2008_INTERVIEW]

11.4 Discussion and Conclusion

This research sought to increase pre-service early childhood teachers' confidence to teach science through a collaborative approach between science/engineering academics and teacher educators to develop and implement science modules within a science methods course. Over the science methods course, the pre-service teachers increased their interest in teaching science, knowledge for teaching science, confidence in teaching science and enthusiasm for teaching science. The pre-service teachers identified a combination of reasons that contributed to their increased confidence to teach science: being shown how to teach science, performing science activities, having access to resources and increased science content knowledge. The method in which the modules were implemented into the science methods course provided opportunities for the pre-service teachers to engage in science that they might be expected to teach in the classroom. As Appleton (2003) reported, if this is accompanied with the pre-service teachers being shown why the science they are doing works in both the scientific and pedagogical sense, then they are likely to develop their science PCK. The carefully constructed science learning experiences presented in both the modules and science methods course assisted in the ongoing development of the pre-service teachers' science PCK.

Notably, the pre-service teachers did not consider science content knowledge to be the most important reason for their increased confidence. This supports the findings of Howitt (2007) who reported that science pedagogy and science activities were considered more important than science content knowledge in improving pre-service elementary teachers' confidence. Pre-service teachers value experiences that are directly transferable into the classroom. Thus, they value knowledge of science pedagogy, science activities and science content as a whole, rather than as discrete events. Learning to teach is not a discrete process, rather it is a complex, subtle and continuous process that requires different forms of knowledge (Wideen et al. 1998).

Pre-service teachers reasons for increased knowledge and understanding of science were attributed to active participation within the workshop where they experienced first-hand authentic science activities for the early childhood classroom; access to the science/engineering academics in the workshops to clarify points and ask additional questions relating to science content knowledge and to procedures related to activities; and access to the modules which had a wide range of information relating to activities, resources, science knowledge and integration. Many pre-service teachers considered the combination of all three factors to be integral to their knowledge of science. This further reflects the holistic approach of learning how to teach science which pre-service teachers appear to require. This holistic approach is also supported when interpreting the pre-service teachers' content learnt from the workshops in which a science/engineering academic participated. Learning was not restricted to science content knowledge. Rather, the pre-service teachers recognized pedagogical content and application to an early childhood context. The results from this research highlight the holistic and integrated approach that pre-service early childhood teachers take in their learning. If this is how they are learning, then this should also be the approach to teach them within the science methods course.

The experiences within, and confidence from, the science methods course were transferred across to the pre-service teachers teaching practice. Over 60% of the pre-service teachers had used the modules to prepare their science lessons, with more than half of these being prepared to modify the activities within the modules for their own context. The modules had been used in the manner for which they were designed: as an adaptive and flexible tool for early childhood science teaching and learning.

This research has found that a collaborative approach between teacher educators and science/engineering academics to develop and deliver science curricula has assisted early childhood pre-service teachers to increase their interest, confidence and enthusiasm for teaching science, along with their science content knowledge. This approach to teacher education has increased the pre-service teachers' accessibility to science and encouraged the teaching of science within the early childhood classroom.

Acknowledgements This research was made possible by funding obtained through the Australian Learning and Teaching Council, Grant Number CG8-724. Thanks are extended to all the pre-service early childhood teachers who participated in this research through the development of the modules and subsequent evaluation in the classroom.

References

Appleton, K. (2003). How do beginning primary school teachers cope with science? Towards an understanding of science teaching practice. *Research in Science Education, 33*(1), 1–25.

Appleton, K. (2006). Science pedagogical content knowledge and elementary school teachers. In K. Appleton (Ed.), *Elementary science teacher education. International perspectives on contemporary issues and practice* (pp. 31–54). Mahwah: Lawrence Erlbaum Associates.

Australian Academy of Technological Sciences and Engineering (ATSE). (2002). *The teaching of science and technology in Australian primary schools*. Melbourne: ATSE.

Bell, R. L., Blair, L. M., Crawford, B. A., & Lederman, N. G. (2003). Just do it? Impact of a science apprenticeship program on high school students' understandings of the nature of science and scientific inquiry. *Journal of Research in Science Teaching, 40*(5), 487–509.

Cantrell, P., Young, S., & Moore, A. (2003). Factors affecting science teaching efficacy of preservice elementary teachers. *Journal of Science Teacher Education, 14*(3), 177–192.

Crawford, B. (2009, November). Moving science as inquiry into the classroom: Research to practice. In M. Kim, S. Hwang, & A. Tan (Eds.), *Proceedings of the International Science Education Conference. Science Education: Shared Issues, Common Future* (pp. 574–599). Singapore: National Institute of Education.

Drayton, B., & Falk, J. (2006). Dimensions that shape teacher-scientist collaborations for teacher enhancement. *Science Education, 90*(4), 734–761.

Enochs, L. G., & Riggs, I. M. (1990). Further development of an elementary science teaching efficacy belief instrument: A preservice elementary scale. *School Science and Mathematics, 90*(8), 694–706.

Fleer, M. (2006). "Meaning-making science": Exploring the sociocultural dimensions of early childhood teacher education. In K. Appleton (Ed.), *Elementary science teacher education. International perspectives on contemporary issues and practice* (pp. 107–124). Mahwah: Lawrence Erlbaum Associates.

Ginns, I. S., Watters, J. J., Tulip, D. F., & Lucas, K. D. (1995). Changes in preservice elementary teachers' sense of efficacy in teaching science. *School Science and Mathematics, 95*(8), 394–400.

Goodrum, D., & Rennie, L. (2007). *Australian school science education: National action plan 2008–2012: Vol. 1. The National action plan.* Canberra: Department of Education, Training and Youth Affairs. http://www.dest.gov.au/sectors/school_education/publications_resources/profiles/Australian_School_Education_Plan_2008_2012.htm

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools: A research report*. Canberra: Department of Education, Training and Youth Affairs.

Harlen, W., & Holroyd, C. (1997). Primary teachers' understanding of concepts of science: Impact on confidence and teaching. *International Journal of Science Education, 19*(1), 93–105.

Howes, E. V. (2002). Learning to teach science for all in elementary grades: What do preservice teachers bring? *Journal of Research in Science Teaching, 39*(9), 845–869.

Howitt, C. (2007). Pre-service elementary teachers' perceptions of factors in an holistic methods course influencing their confidence in teaching science. *Journal of Research in Science Education, 37*(1), 41–58.

Howitt, C. (2009). 3-D mind maps: Placing young children in the centre of their own learning. *Teaching Science, 55*(2), 42–46.

Howitt, C., & Blake, E. (2010). *Planting the seeds of science: A flexible, integrated and engaging resource for teachers of 3 to 8 year olds*. Sydney: Australian Learning and Teaching Council.

Howitt, C., Lewis, S. W., & Waugh, S. (2009). Analysis of an exemplary scientists in schools project in forensic science: Collaboration, communication and enthusiasm. *Teaching Science, 55*(3), 46–51.

Huinker, D., & Madison, S. K. (1997). Preparing efficacious elementary teachers in science and mathematics: The influence of methods courses. *Journal of Science Teacher Education, 8*(2), 107–125.

Martin-Dunlop, C., & Hodum, P. (2009). Scientist-science educator collaborations: Do they improve students' understanding of the nature of science? *Journal of College Science Teaching, 39*(2), 66–75.

Mulholland, J., & Wallace, J. (1996). Breaking the cycle: Preparing elementary teachers to teach science. *Journal of Elementary Science Education, 8*(1), 17–38.

Mulholland, J., & Wallace, J. (2003). Crossing borders: Learning an detaching primary science in the pre-service to in-service transition. *International Journal of Science Education, 25*(7), 879–898.

Palmer, D. (2006). Sources of self-efficacy in a science methods course for primary teacher education students. *Research in Science Education, 36*(4), 337–353.

Rice, D. C., & Roychoudhury, A. (2003). Preparing more confident preservice elementary science teachers: One elementary science methods teacher's self-study. *Journal of Science Teacher Education, 14*(2), 97–125.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(1), 4–14.

Stringer, E. (2008). *Action research in education* (2nd ed.). Upper Saddle River: Pearson Prentice Hall.

Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Melbourne: Australian Council for Educational Research.

Watters, J. J., & Ginns, I. S. (2000). Developing motivation to teach elementary science: Effect of collaborative and authentic learning. *Journal of Science Teacher Education, 11*(4), 301–321.

Wideen, M., Mayer-Smith, J., & Moon, B. (1998). A critical analysis of the research on learning to teach: Making a case for an ecological perspective on inquiry. *Review of Educational Research, 68*(2), 130–178.

Zeidler, D. L. (2002). Dancing with maggots and saints: Visions for subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge in science teacher education reform. *Journal of Science Teacher Education, 13*(1), 27–42.

Chapter 12
Stories of Teaching Hypothesis-Verification Process in Elementary Science Classrooms

Mijung Kim, Yong Jae Joung, and Hye-Gyoung Yoon

12.1 Introduction

There have been various forms and approaches of inquiry-based teaching to enhance children's scientific mind and skills since scientific inquiry is recognized as one of the main goals in science education (AAAS 1989; Crawford 2007; NRC 1996, 2000). Among various approaches of inquiry teaching, hypothesis-based inquiry has been recognized as an effective way to develop children's scientific reasoning and problem solving in science teaching. Studies suggested that hypothesis construction and evidence-based reasoning can be taught to young children (Jeong et al. 2007; Joung 2008; Tytler and Peterson 2003), yet there are pedagogical concerns in its implementation in classrooms. First, even though hypothesis is the central part of investigative process, the definition and role of hypothesis have not been examined thoroughly among science educators and teacher practitioners (Wenham 1993); thus, it has been difficult to agree on its practice and outcomes accordingly. Second, there has not been sufficient discussion on pedagogical framework and practice of hypothesis-based inquiry teaching in classroom settings. In this regard, this study attempts to raise some pedagogical issues of hypothesis-based inquiry in preservice teachers' classroom practice. To do so, we start to examine the nature of hypothesis and verification.

M. Kim (✉)
Curriculum and Instruction, University of Victoria, Victoria, BC V8W 3N4, Canada
e-mail: mjkim@uvic.ca

Y.J. Joung
Science Education, Gongju National University of Education, Gongju, South Korea

H.-G. Yoon
Science Education, Chuncheon National University of Education, Chuncheon, South Korea

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_12,

12.1.1 The Nature of Hypothesis Verification

Hypothesis is the principle intellectual technique of investigation in the history of scientific development (Hanson 1958; Lawson 1995). For instance, Kepler's explanation of the features of Mars' orbital and Galileo's discovery on constancy of gravitational acceleration are the examples of scientific discoveries conducted by generating hypothesis. These discoveries were made neither by just interpreting mathematically the necessary consequence of hypothesis, that is, deductive inference, nor by extracting mechanically a common factor from collected observations, that is, inductive inference. They were discovered by generating hypothesis based on abductive inference that goes beyond the information in prior data (Hanson 1958). Scientists construct hypotheses based on the phenomena they observe and carry out numerous experiments to test their hypotheses throughout the history of science, for example, Loffler and Roux's hypothesis and test on diphtheria and the therapeutic use of antiserum resulted in a significant development of germ theory in medical science history (Beveridge 1961). A good hypothesis indeed brings out an important contribution to scientific development. A good hypothesis, at first, is *a* hypothesis, but eventually transformed into a theory through evidence afforded by subsequent investigation (Lawson 2003). If the hypothesis holds right explanation for all situations, it can be evaluated as a theory or law if sufficiently profound (Beveridge 1961).

There have also been wrong hypotheses which have led fruitful scientific development in the history. For example, in Western Australia, H. W. Bennet made a hypothesis that neurodisease of swayback (sheep) was due to lead intoxication and carried out his tests with ammonium chloride which is the antidote to lead. However, his test results made him doubt about his initial ideas. The disease was not always cured by ammonium chloride. Thus, he constructed another hypothesis that the disease might be due to deficiency of some mineral which was present in the first batch of ammonium chloride, not ammonium chloride itself. Bennet soon found out that the neurodisease was due to deficiency of copper, a deficiency never previously known to animal's disease. This case indicates that scientific development can also result from a false hypothesis and the importance of critical analysis of test results and reexamination of hypotheses.

The structure of hypothesis as conjecture of phenomena and experimental design as method of dealing with evidential phenomena must be suitable for each other's end. In other words, the following tests must be purposefully designed and practiced to verify the explanations. Without the connection between hypothesis and tests, hypotheses cannot be proved and experiments become disconnected with no outcomes or benefits to accepting or refuting the hypotheses. In the understanding of the purpose of experiments, there requires critical and open-minded approaches to our hypothesis in data interpretation. Beveridge (1961) explicitly mentioned that "we must strive to judge the data objectively and modify or discard it as soon as contrary evidence is brought to lift. Vigilance is needed to prevent our observations and interpretations being biased in favour of the hypothesis" (p. 52). That is, we need to design experiments and methods based on presupposition that our hypothesis is true and yet, collect and interpret data without overinclination to the hypothesis. The data interpretation and analysis must require critical, open-minded approach.

With the importance of hypothesis-verification process in science communities, hypothesis-based approach has been practiced in science classrooms, especially in the area of problem solving, scientific explanation, and argumentation. Hypothesis plays a central role in posing and articulating the aspiration and direction of problems (Lawson 1995, 2003; Klahr and Dunbar 1988), in collecting and analyzing data systematically (Hempel 1966; Wenham 1993), and in explaining why problematic phenomena happen (Hanson 1958; Millar 1989). Therefore, hypothesis plays a central role in learning problem-solving process as well (Lawson 1995). To implement this method effectively in classrooms, it is crucial for teachers to understand how to construct hypothesis and how to test and analyze test results in investigative inquiry. However, the understanding of hypothesis has been perplexing and challenging among science educators with multiple aspects of assumption, tentative explanation, tentative cause, tentative law, and prediction (Jeong and Kwon 2006; Yoon et al. in press). For example, hypothesis and prediction are used occasionally for the same purpose without understanding the role of hypothesis and prediction, that is, to answer to the questions “why it happens?” or “what will happen?”. Especially in elementary levels, prediction was suggested as hypothesis considering the level of students’ conceptual knowledge and capacity of problem solving (Gilbert and Matthews 1986). Because of the multiple understanding of hypothesis, the approach of hypothesis-based inquiry has also been practiced in various formats and directions.

In this work, we take the view of hypothesis as a tentative explanation. Hypothesis as tentative/suggested explanation or solution is the one most widely used in science education (Park 2006; Wenham 1993). It is a tentative explanation when we encounter an unusual situation and try to make sense of the unusualness (Peirce 1998). In other words, hypothesis is a kind of tentative answer to the question “why a present phenomenon happens?” (Lawson 1995; Salmon 1998). Based on tentative explanation or solution, students predict results and determine what to observe based on variables. They collect data and interpret and make a conclusion tightening the original explanation and data collected. Without this tentative explanation or solution, students’ hypotheses in science classrooms turned out to be a simple prediction on what will happen in the end. Lawson (1995) explained that “prediction” is a thing that is posed from hypothesis by deduction, is to be compared with the result of experiment, and then is to verify the hypothesis by inductive process. Thus, hypothesis is different from prediction. It requires a certain process of logical thinking to presuppose reasons of prediction. We in this study, attempt to differentiate hypothesis from simple prediction and highlight that without understanding the nature of hypothesis, hypothesis-based inquiry cannot sufficiently develop scientific reasoning and evidence-oriented mind theoretically expected in hypothesis-verification approach. To claim this notion, we will discuss some episodes of teaching scenes later on in this chapter.

To discuss the challenges of the nature of hypothesis and verification practiced in classroom teaching, this study examines how preservice teachers implement this approach in elementary science classrooms and what difficulties and conflicts emerge during their practice. Observing their teaching practice and reflecting together with the preservice teachers, we attempt to understand the challenges of hypothesis-based inquiry teaching in classroom practice and ways of helping preservice teachers with understanding hypothesis-based inquiry.

12.2 Research Method

12.2.1 Research Context

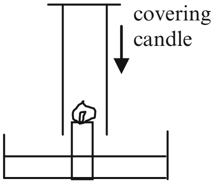
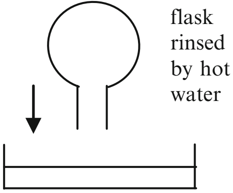
To understand the dynamics of teaching hypothesis-verification process in elementary science classrooms, we invited fourth-year university students (preservice teachers) in elementary science methods course in this study. Sixteen preservice teachers were asked to design inquiry-based science lessons, teach them to elementary students, and reflect their lessons during 15 weeks of their course work. From the first to sixth week of the course, the preservice teachers were engaged in exploring teaching strategies to help children with problem-solving process based on hypothesis making, designing experiments and controlling variables, collecting data, and making a conclusion. In the seventh to ninth week, the preservice teachers were divided into three groups and collaboratively designed one inquiry lesson per group. They chose lesson topics that they thought were the most suitable and interesting for children's inquiry learning. All three groups developed an inquiry lesson based on hypothesis-verification process. In Lesson 1 "snowman's coat", elementary students needed to figure out how they could keep ice cream (popsicles) from melting longer. The students observed their popsicles for 10 min in three conditions: leaving it as it is, fanning it, and wrapping it with cloth. Lesson 2 was "paper spinner and hoop plane." The students were asked to make their own hypotheses of what makes the objects fly longer. Lesson 3 was "candle flame and rising water." Students were asked to find out under what condition and why water level goes up higher after candle flame goes off inside of cylinder. Children came up with the number or length of candles as variables in their hypothesis testing. Among three lessons, we explain the details of lesson 3 below (see Table 12.1). Because stories from lesson 3 distinctively explain the issues of hypothesis-based inquiry teaching than the other two lessons[1] (see Table 12.1).

To carry out more effective lessons for children, the preservice teachers practiced inquiry activities beforehand to develop inquiry teaching strategies and reduce any anticipated errors. From the tenth to thirteenth week, they taught their lessons to 18 elementary students in a special interest group in science. The class was a mixed group of students in grades 4, 5, and 6. The preservice teachers taught their lessons

---

[1] We have discussed lessons 1 and 2 more in detail to discuss the difficulties of inquiry teaching in our other work (Yoon et al., in press). In this chapter, we particularly focus on the issues of hypothesis-verification process in the cases of lesson 3.

Table 12.1 The sequence of lesson 3, "*the candle flame and rising water*"

Process	Activities	Video clips in the lesson
Introduction	A video clip of burning candle and covered by a cylindrical glass Children observe and discuss why the water is rising after the candle went off	Video clip 1 
Hypothesis making	Children in four groups make hypothesis on under what condition water will go inside more Children presented their hypothesis to the whole class. They explained their ideas based on oxygen consumption	
Testing	Children design their experiments with variables and constants based on their hypothesis and conduct test	
Data interpretation	Children collect data and examine if their hypothesis was right. They make conclusions	
Presentation	Children present their results and conclusion to the whole class	
Ending video	Teacher shows another video clip of rising water inside flask, but with no candle flame involved Teacher explains that the main reason of water level rising was heat (temperature change), not oxygen consumption	Video clip 2 

as team once a week. The class last 1 h and 30 min each time. After the classroom teaching, the preservice teachers returned to the university and had discussion on their experiences of preparing and teaching their lessons for the last 2 weeks (14th–15th week).

12.2.2 Data Collection and Analysis

In order to understand problems and difficulties of hypothesis-based teaching, we videotaped the preservice teachers' classroom teaching and group discussion to closely look into their decision making and actions. The data from group discussion was used to understand their actions in depth. In data analysis, we modified and employed the process of open coding, axial coding, and selective coding originally suggested by Glaser and Strauss (Flick 2006), which we found useful to search for integrated themes and relationships among research data. This helped us understand the phenomena of hypothesis-verification teaching practice more coherently and thematically. Open coding was done individually. Through the preservice teachers' reflection in group discussion, we could also understand why their actions occurred in certain ways during lessons. Themes from the group discussion were cross-checked with the video data of their teaching.

For axial coding, we gathered to discuss our individual interpretation, themes, and concerns related to the data. During this step, we discussed what would be the similarities and differences in our interpretation and thematization to find out integrated, coherent themes and concerns of hypothesis-based teaching. We watched the video clips to discuss the different views and modified our themes.

For selective coding, we selected some episodes from lesson 3, and discussions which we agreed distinctively exhibited the concerns and difficulties of teaching hypothesis-based inquiry. Then, we discussed the details of preservice teachers' experiences, decision-making scenes, and actions in the episodes to reexamine the themes and the contexts of the episodes. This process of coding by comparing and cross-checking the data from different sources helped us understand the relationships of their decision making and action which we could not recognize from one source of data. By following those steps, we could analyze and conclude the integrated themes of the difficulties and concerns of hypothesis-based inquiry in classroom teaching.

12.3 Research Findings

In this study, we found several pedagogical difficulties in teaching hypothesis-based inquiry in elementary science classrooms. We attempt to highlight the difficulties in three stages of the teaching of scientific investigation: (1) hypothesis construction, (2) experimental design and test, and (3) data interpretation. In hypothesis construction, we discuss the lack of understanding hypothesis. In the stage of experimental design and test, we argue that it is important to understand the roles of testing in teachers' practice. Lastly, we discuss that teachers need to develop their pedagogical skills to encourage children's data interpretation and analysis based on experimental results.

12.3.1 Lack of Understanding of Hypothesis

Hypotheses require tentative and testable explanation to given problems in order to develop an investigative process. That is, constructing a hypothesis can be the beginning of good investigative inquiry. However, the preservice teachers seemed to have difficulties to understand what would be suitable forms of hypothesis to lead hypothesis-verification process more fruitful and scientific. During the lessons, they asked children to predict the result of given problems as hypothesis making. Children wrote down what would happen in the end without thinking or explaining why it would happen. Their hypothesis making did not include a tentative explanation to the given problem. In this case, children's hypothesis is only a simple prediction, not a hypothesis. For instance, in the first lesson (snowman's coat) led by the first group of preservice teachers, children were asked to predict in which way they could keep ice bars the longest without melting among three options (fanning, leaving with no interruption, and wrapping with cloth). Children made a hypothesis such as "when we fan on it, it will melt the fastest." In the second lesson (paper spinner and hoop plane), children were asked to fill in the blank on the sentence, "when wings are _______, paper sinners will fall down slowly." Among four groups of children, three groups made a hypothesis that "the longer wings are, the more slowly paper spinners will fall down." And one group said, "when the wings have an appropriate length, the spinner will fall down slowly" without further explanation on what appropriate length meant.

In lesson 3 (candle flame and rising water), children's hypothesis making seemed a bit more appropriate in terms of including tentative explanation. The third group of preservice teachers guided children to come up with possible reasons for their prediction on candle and rising water. Here are the details of children's hypothesis making in lesson 3 (Episode #1).

12.3.1.1 Episode #1

Two preservice teachers, Tae and Kang, were team-teaching in this lesson. Tae taught the first half and Kang taught the second half. The two other preservice teachers in this group were helping children's group work. In the beginning of the lesson, Tae showed a video clip of a burning candle on a petri dish half-filled with water. Then later, the candle was covered with a measuring cylinder. Children observed the candle flame go off and the water level inside the cylinder rise. Tae attempted to guide children's discussion on their observation. He asked:

Classroom dialogue #1

Tae (teacher): Why do you think the water level has gone up inside the cylinder? Could you write down your thinking and present it to the class?

(A few minutes later, Tae asked what students wrote.)

Student group 1: We thought it is because the air disappears because of the candle flame and the water was replacing the space of the air.

Tae: Ok, good work. What about next group?

Student group 2: It is because oxygen will be consumed and there will be empty space. The water went into the cylinder to fill the space.

Tae: Ok, next group, are you ready? All right. Tell us your thought.

Student group 3: There is difference of air pressure inside the cylinder. And, oxygen disappears and the water is sucked in to replace the space.

[Omission]

Student group 4: Oxygen disappears so the water goes in to fill the space.

Tae: Ok, good work, guys. Now I am going to ask you to think of how you can make the level of water higher inside the cylinder.

Later, Tae asked children to make hypotheses, suggesting the sentence of "when_____, the water level goes up higher because_____." Three groups of students said that "the more candles are inside, the higher water level will be because they will consume more oxygen." One group (student group 3) presented a different condition. They suggested that "the longer the candles are, the more water will go inside because carbon dioxide is heavier than the air and can extinguish the flame. In this case, the flames can stay longer." But their explanation was also based on the idea of oxygen consumption inside the cylinder, as shown in the Classroom dialogue #1.

After the lesson, the researcher and the preservice teacher have a time for reflective discussion on the lesson. During reflective discussion, the preservice teachers showed their views of hypothesis that is different with the researcher's, as shown in the dialogue below.

Reflective discussion #1

Researcher: You asked them to write a hypothesis? And what else?
Shin: Before that (making hypothesis), we asked them to think of reasons and write them down on their individual worksheet.
Researcher: So it was writing a hypothesis?
Jin: No, before making hypothesis.
Shin: Through the activity sheet, they could understand the problem….
Jin: And the reason why the water level rises.

This episode exhibits a few difficulties in the preservice teachers' teaching of hypothesis making. First, the preservice teachers who taught this lesson understood a prediction as hypothesis similarly to preservice teachers in the 1essons 1 and 2. Although the suggested format of hypothesis making consisted of two parts (the first part is for "prediction," the second part is for "the reason of the prediction," that is, "hypothesis"), the preservice teachers regarded the first part, "prediction," as hypothesis (see Reflective discussion dialogue #1).

Second, this view of hypothesis in the preservice teachers' understandings caused their misunderstanding of the purpose of a "test". The purpose of a test in the process of hypothesis verification is to test the hypothesis, i.e., tentative explanation. The preservice teachers, however, did not examine whether the experiments designed by the children is suitable for testing the hypothesis, "oxygen consumption" (see Classroom dialogue #1 and Episode #2 for more details). Rather, they just tried to observe the results of experiments. That is to say, they attempted to test just a prediction, "the more candles are inside, the higher water level will be." Actually, it is not easy to test directly the hypothesis "oxygen consumption" by measuring the amount of oxygen inside the cylinder, because there were not sufficient equipment or materials in the classrooms. The preservice teachers could have considered if there was any available method to test the hypothesis, not the prediction itself, and have guided children to design an experiment to test their hypothesis. The preservice teachers in the episode, however, did not seem to realize these points. They did not understand the role of test in hypothesis-verification process. We will discuss this in details in the following section.

12.3.2 Understanding the Roles of Test

To justify a hypothesis, there requires a fair test. To attain the fairness of test is to plan and control the variables and constants which could verify the tentatively argued explanation in the hypothesis. In this way, hypothesis could be reexamined and improved. For example, if the suggested hypothesis is “when there are more candles, the water level goes up higher because they consume more oxygen,” then a test needs to be designed to verify “more oxygen consumption and higher water level.” And yet, the preservice teachers did not have sufficient understandings of the role of test in hypothesis-verification process and the connection between hypothesis and test. The lack of these understandings led children’s work not fruitful. In lesson #3, children’s test with the different numbers of candles could prove that their prediction (the more candle, the higher water level) turned out to be right, however, could not verify their explanation (because of oxygen consumption). Here are more details of the notion.

12.3.2.1 Episode #2

After children made their hypothesis such as “the more candles, the higher water level because of oxygen consumption” in the student groups 1, 2, and 4 and “the longer candles, the higher water level, because carbon dioxide is heavier than the air” in the student group 3, the teacher asked children to deign experiments to test their hypotheses. Children set up their tests based on variables and constants and started testing their hypothesis out. In their testing, what students actually observed was that the water level went higher when there were more candles. In other words, in their approach, the test seemingly confirmed that their hypothesis was true. Children concluded the experimental result showed that their hypothesis was right. While children were writing up the results, Kang took over the next part of the lesson from Tae. Then she asked children to present their findings and conclusion. After three groups presented, a boy from the student group 4 is presenting their group work.

Classroom dialogue #2

Kang: Let’s hear about the last group’s conclusion.

Boy 1: We thought that when there are more candles, the more water will go inside because when the candles are burning, carbon dioxide will come out and the density of carbon dioxide is bigger than oxygen and any other gas inside the cylinder. So there will be some empty space and the water will be sucked in to replace the space.

Boy 2: Therefore, we tried to test cases with 1, 2, 3, and 4 candles. We made the same the amount of water [in the petri dish], the size of cylinder, the length of the candles, and the time we cover the cylinder…Errr, we could not do the case of 4 candles. The level of water was 5 cm for 1 candle, 6 cm for 2 candles, 7 cm for 3 candles. We did not have time for 4 candles.

The result of student group 3 also showed their hypothesis (strictly speaking, prediction) was right. After the last group finished their presentation, Kang realized the process was ended with something that her group did not anticipate. Kang realized that children were getting wrong ideas that the water level goes up mainly because oxygen is consumed and water is replacing the space of oxygen. She attempted to teach children the "correct" reason for the phenomenon and concluded the session with the following remarks.

Classroom dialogue #2.1

Kang: To sum up your hypothesis and conclusion, most of you thought that the candles are using oxygen and the water goes inside to replace the empty space. So you designed your test and carried it out. However, think about what you observe on the video in the beginning. If it is because of oxygen consumption, the candle flame is continuously consuming oxygen, the water would go up gradually. However, on the video, you saw the water was suddenly going up very high after the flame was off.

A boy: Because of heat…

Kang: Then, we thought it was related to oxygen… let's watch one video clip to think about other reason.

She showed children a video clip (video clip 2 in Table 12.1) that her group had prepared beforehand. The video clip showed a demonstration of which a teacher rinses a round flask with hot water and puts it upside down on a petri dish half-filled with water. There was neither candle nor flame involved in the demonstration, so there should be no activities of combustion and oxygen consumption. By showing this video clip, the preservice teachers attempted to explain the relationship between water rising and heat (temperature). The lesson was ended without further discussion on children's experiment and conclusion by showing the video clip (refer to Table 12.1).

In hypothesis-making, a tentative explanation is built by abductive inference based on one's experiences, observation, scientific knowledge, and so on and a prediction can be led deductively from this tentative explanation (Hanson 1958; Lawson 1995). Afterward, a test will prove the prediction right or wrong and thus verify the tentative explanation. In the case of lesson 3, since the prediction did not stem deductively from the tentative explanation, it could not play a significant role to verify hypothesis through test. It also seemed that the preservice teachers did not recognize what children's tests would prove was not only the prediction part (the more candle, the higher water level) but also the explanation part (oxygen consumption) which is essential to verification of hypothesis. We could argue that if the preservice teachers had understood this role of test, they could have rethought children's making hypothesis and designing test. But it was not the case. Without any teachers' guide on hypothesis making or planning for test, children carried out their test and attempted to oververify their hypothesis based on test results (Episode #2). The collected data and test results were not sufficient to prove whether the reason for the rising level of water was oxygen consumption or something else (e.g., heat or air temperature). The independent variable (the numbers of candles) and dependant variable (water levels) are enough to prove the prediction, but unsatisfactory to explain the reason (the amount of oxygen).

In hypothesis-verification process, designing valid tests is a critical process to verify hypothesis. The variables on tests need to be designed to examine tentative explanations that investigators presuppose. Even though the preservice teachers in lesson 3 encouraged children to come up with temporary explanations, there was no deep understanding in which test also needed to take into consideration the explanation, not only prediction. They did not realize that the variables in children's experimental design, for example, the number or length of candles, could not justify the hypothesis as a whole (prediction and explanation). And yet, we do not argue that it is meaningless to have hypotheses which cannot be justified by test or constructed based on wrong concepts in the first place. Through thorough test design and discussion process, the hypothesis will be revised or eventually proved wrong, and it could lead further scientific thinking. However, without appropriate pedagogical scaffolding, hypothesis-verification inquiry process would be unfruitful and might result in perplexing results of knowledge and inquiry skills.

12.3.3 Skills of Data Analysis and Discussion

In hypothesis-verification process, data collection and interpretation are critical for the evidence of scientific explanation. This study showed how difficult it is for preservice teachers to help children analyze or interpret experimental data on site. In actual classroom teaching, the data collected and interpreted by children were rather unpredictable and, thus, the preservice teachers seemed not prepared to scaffold the process of analysis and conclusion based on test results. In all three lessons, data interpretation and analysis were not taken thoroughly to discuss the relationships among test results, conclusion, and scientific knowledge. The following episode shows that there was not much learning of data analysis.

12.3.3.1 Episode # 3

Children in the student group 3 made a hypothesis that the longer candles were, the more water goes in, because when the candle is longer, it will take more time that CO_2 will cover the candle frame. They continued to explain that it helps the candles consume more O_2 so there will be more empty space. They also thought that the density of CO_2 is denser than O_2; therefore, even if CO_2 is produced from combustion, there will still be some empty space. Then they set up a test and collected their data with different lengths of candles. Their results showed that when the length of candle was 5 cm, 8 cm, 11 cm, 14 cm, and 17 cm, the level of water was 6.1 cm, 6.5 cm, 5.2 cm, 5.4 cm, and 5.2 cm, respectively. The children presented their result by using a table and graph.

Classroom dialogue #3

Boy 2: To conclude, differently from our hypothesis, when the length of candle is not too long, not too short, but proper, the level of water is the highest. That [the proper length of candle] was 8 centimeters.

Kang: So you thought in the beginning that when the candle was longer, water would go up more. Why did you think that way?
Boy 1: errr… ummmm….
Boy 2: Because if the candle is longer, it will take longer time that carbon dioxide reaches the flame, um…and the water also goes up gradually and…so, it will take longer time to reach the flame.
Kang: So you thought the short candle will go off early because carbon dioxide reaches it first so only little water goes in [to the cylinder], is it?
Boy 2: Yes.
Kang: But in your results, it says that longer candles did not have more water in, ya? The 8 cm candle got the highest water level?
Boy 2: Yes…
Kang: Okay, thanks. Please, group 4 [next group], could you come out and present your work?

The teacher moved on to the next step without any discussion on this notion.

In this episode, the children's result was worth a further discussion. The preservice teacher could have encouraged the children to examine why their hypothesis was not true or if they would want to change or revise their hypothesis or test setting. However, just confirming the results without any further discussion or questions, the preservice teacher moved onto next step to get other group to present their results. This notion of lack of data interpretation appeared in all three lessons that the preservice teachers conducted in this study. They did not show much time and effort in interpreting and analyzing data together with children. If the preservice teachers had asked children to discuss why the results were different from what they expected, it could have generated and developed more reasoning skills and scientific minds to look into the relationships between the phenomena and knowledge. For instance, if the preservice teacher asked the children "why were the results different from what you expected?" the children might explore various reasons and activities such as the following: "because the difference between density of CO_2 and O_2 has not critical influence dissimilarly to our expectation. It needs to reconsider our hypothesis," "because there might be measuring error or noise effects that we did not expect. To do confirm these ones, we need other experiment settings, for example, with bigger/smaller cylinder. In addition, we need to have more articulated measuring tools and skills," and so on. There were not enough awareness and scaffolding of the teachable moment to fulfill the aspects of investigative inquiry process and developing children's learning and knowing.

12.4 Discussion

Based on the findings, we highlight the difficulties of teaching hypothesis-based inquiry in the dimensions of the nature of hypothesis, role of test, and skills of data analysis and interpretation. First, there needs to be a sufficient understanding of the nature of hypothesis to conduct a hypothesis-verification inquiry effectively. If there is one sentence, one observation, or one single inference about a single concrete object with no testable explanation in hypothesis making, the statement is not sufficient to become a hypothesis (Quinn and George 1975). And testability of a hypothesis depends on whether the hypothesis has observable predictions that can verify the hypothesis, not on whether the prediction is just observed. In this study, because the preservice teachers did not fully understand the distinction between simple prediction and hypothesis (see the Episode #1), the process of hypothesis verification became a simple observation on the test result, not being able to test and understand scientific explanation in the phenomena (see the Episode #2). To enhance higher level of thinking and reasoning, teachers need to understand the nature of hypothesis in their teaching.

Second, there needs to be more understanding of the role of test in hypothesis-verification process. Studies explain that hypothesis leads us to decide what to be observed (as well as how, when, and where) and which variables are likely to be significant to justify hypotheses (e.g., Wenham 1993). This draws our attention to the coherent link between tentative explanation and prediction as well as hypothesis and following test. In this case, the fairness of test is to take account into not only the skills of controlling variables fairly but also the connection of hypothesis and test. Without the thoughtful thinking process between them, the process of hypothesis verification became disjointed work with irrelevant data and explanation to certain phenomena. Test is not only a straightforward observation on what is happening during experiment. This also means that variables and constants in the test need to take into account the explanation suggested in the hypothesis. If we intend to enhance the value of fair test, the variables and constants need to be controlled in the connection to what needs to be observed and tested. For instance, children's test on candle flame and rising water could verify the part of prediction (the more candle, the higher water level) without taking into consideration the explanation (because of the oxygen consumption). In this case, the fairness of test needs to be reexamined to test a hypothesis as a whole.

Third, teachers also need to know how to scaffold children's data analysis and interpretation to make conclusions. Data collecting and interpretation based on evidence are the essential components of scientific investigation and reasoning; however, the connected examination between primary data and the statement of results has been often ignored in the process of scientific reasoning (Kanari and Millar 2004). In this study, children simply presented the summary of their findings and teachers accepted children's presentation as analysis and conclusion without further discussion. In the end, the children in the study miss an opportunity to experience the essential components of scientific investigation. In the discussion of data interpretation and conclusion, teachers also need to understand the dynamics of children's communication, as fundamental nature of scientific knowledge development to guide children's scientific attitudes (Scott et al. 2006) and the value of sharing plural accounts as collectives in groups to enhance the abilities of data analysis, conclusion, and scientific argumentation (Duschl and Osborne 2002; Kelly et al. 2001). We believe that the preservice teachers' understanding of hypothesis-verification process and pedagogical decision making and skills will be improved over time, yet it is only possible through the reiteration and critical reflection on their practice of hypothesis-based inquiry teaching in classrooms. There needs to be more integrated approach to understand the dynamics of teachers' understanding and practice of hypothesis-based inquiry teaching in further research.

12.5 Concluding Remarks

Hypothesis-verification process is beneficial to enhance children's scientific minds and problem-solving skills. Being engaged in the process, children learn how to make hypothesis, design experiment test their hypothesis, and reach conclusion. However, to make the process fruitful and valid, more systemic and disciplined instruction is required to develop children's reasoning and skills of evidence-based scientific investigation. The process of hypothesis verification is not simply "predicting what" but "explaining why" on given problems. Teachers' understanding and decision making on how to intervene or guide children's work would be challenging without sufficient understandings of the nature of hypothesis and the roles of test. To aim for the development of higher level of scientific thinking and problem-solving skills, this study suggested that teachers' appropriate pedagogical actions based on their understandings of hypothesis, test, and analysis would be essential. And yet, this study still remains some issues of the readiness of children's cognitive ability and the levels of scientific-thinking skills in elementary classrooms. Distinguishing simple prediction from hypothesis in elementary levels might be argued as an unnecessary challenge for teachers as well as children; however, we believe that this argument needs to be rethought for elementary science education to evoke children to seek for evidence to claim for their ideas.

References

American Association for the Advancement of Science. (1989). *Science for all Americans: Project 2061*. New York: Oxford University Press.

Beveridge, W. (1961). *The art of scientific investigation*. London: Mercury Books.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching, 44*(4), 613–642.

Duschl, R. A., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*(1), 39–72.

Flick, U. (2006). *An introduction of qualitative research*. London: Sage.

Gilbert, C., & Matthews, P. (1986). *Look! Primary science: Teacher's guide A*. Edinburgh: Oliver and Boyd.

Hanson, N. R. (1958). *Patterns of discovery*. Cambridge: Cambridge University Press.

Hempel, C. G. (1966). *Philosophy of natural science*. Englewood Cliffs: Prentice Hall.

Jeong, J.-S., & Kwon, Y.-J. (2006). Definition of scientific hypothesis: A generalization or a casual explanation? *Journal of the Korean Association for Research in Science Education, 26*(5), 637–645.

Jeong, H., Songer, N., & Lee, S.-Y. (2007). Evidentiary competence: Sixth graders' understanding for gathering and interpreting evidence in scientific investigation. *Research in Science Education, 37*(1), 75–97.

Joung, Y. J. (2008). Cases and features of abductive inference conducted by a young child to explain natural phenomena in everyday life. *Journal of the Korean Association for Research in Science Education, 28*(3), 197–210.

Kanari, Z., & Millar, R. (2004). Reasoning from data: How students collect and interpret data in science investigations. *Journal of Research in Science Research, 41*(7), 748–769.

Kelly, G., Crawford, T., & Green, J. (2001). Common task and uncommon knowledge: Dissenting voices in the discursive construction of physics across small laboratory groups. *Linguistics and Education, 12*(2), 135–174.

Klahr, D., & Dunbar, K. (1988). Dual space search during scientific reasoning. *Cognitive Science, 12*(1), 1–48.

Lawson, A. E. (1995). *Science teaching and the development of thinking*. Belmont: Wadsworth Publishing Company.

Lawson, A. E. (2003). The nature and development of hypothetico-predictive argumentation with implications for science teaching. *International Journal of Science Education, 25*(11), 1387–1408.

Millar, R. (1989). What is scientific method and can it be taught? In J. J. Wellington (Ed.), *Skills and processes in science education: A critical analysis* (pp. 47–62). London: Routledge.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academy Press.

National Research Council. (2000). *Inquiry and the national science education standards*. Washington, DC: National Academy Press.

Park, J. (2006). Modeling analysis of students' processes of generating scientific explanatory hypotheses. *International Journal of Science Education, 28*(5), 469–489.

Peirce, C. S. (1998). Abduction. In A. W. Burks (Ed.), *Collected papers of Charles Sanders Peirce* (Vol. 7, pp. 136–144). Bristol: Thoemmes Press.

Quinn, M. E., & George, K. (1975). Teaching hypothesis formation. *Science Education, 59*(3), 289–296.

Salmon, W. (1998) *Causality and explanation*. Oxford University Press: New York.

Scott, P., Mortimer, E., & Aguiar, O. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605–631.

Tytler, R., & Peterson, S. (2003). Tracing young children's scientific reasoning. *Research in Science Education, 33*(3), 433–465.

Wenham, M. (1993). The nature and role of hypotheses in school investigations. *International Journal of Science Education, 15*(3), 231–240.

Yoon, H.-G., Joung, Y. J., & Kim, M. (in press). The challenges of science inquiry teaching for pre-service teachers in elementary classrooms: Difficulties on and under the scene. *Research in Science Education*.

Chapter 13
Pedagogical Practices and Science Learning with a Focus on Educating for Sustainability for Pre-service Primary and Middle Years Educators

Kathryn Paige and David Lloyd

13.1 Background

The pedagogical practices we discuss here are associated with an undergraduate primary (Years 3–5) and middle school (Years 6–9) Bachelor of Education programme (LBPM) offered at the Mawson Lakes campus of the University of South Australia. Graduates are qualified to teach in primary school, junior secondary school and middle schools (Years 6–9). The programme includes four components: educational studies major, curriculum studies, practicum and general studies. The discussion in this paper is concerned with four mathematics/science curriculum study courses which we have designed and managed.

The LBPM programme, which has been offered for the last 5 years, aims to prepare educators who are professionally competent and primarily concerned with learners' well-being and who are committed to social justice, futures thinking, sustainability, education for community living and sound pedagogical reasoning that is enquiry based (University of South Australia 2010). This aim has been informed by a range of interconnected literature and is based on the understanding that globally and locally we are undergoing rapid changes and that past practices are unlikely to meet the needs of immediate- and longer-term futures (Beare and Slaughter 1993; Fensham 2003; Smith 2002; Sterling 2001).

This chapter begins by providing a brief overview of the literature that has informed our approach to teaching and learning science. This in essence provides our theoretical framework. Having outlined the structure of the curriculum courses and key pedagogical practices, we describe four examples of how educating for sustainability is put into practice. To determine the impact our approach has on

---

K. Paige (✉) • D. Lloyd
School of Education, University of South Australia,
Adelaide, SA 5000, Australia
e-mail: kathy.paige@unisa.edu.au

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_13,

pre-service teachers' emerging views about teaching science and mathematics, we analyse course evaluation data from three courses. The concluding remarks provide some insights for future directions.

13.2 Literature That Has Informed the Development of Our Practice

Research literature has informed the development of the programme aim and our pedagogical approach to science and mathematics education. Whilst there is a wide range of possible topics which are relevant to contemporary science education, our professional interests and experience have led us to the following areas: connecting science education to life worlds (Fensham 2003; Goodrum 2006; Harlen 2010; Hodson 2003; Tytler 2007), educating for sustainability (Jones et al. 2010; Jucker 2002; Steele 2010; Sterling 2001; Capra 1996, 2002; Lowe 2009), futures thinking, (Beare and Slaughter 1993; Gough 1990; Gidley 2002; Hicks 2002; Page 1996; Orr 2010), place-based education (Gruenewald 2003; Loeb 2001; Louv 2008; Smith 2002) and transdisciplinary education (Balsiger 2004; Lawrence and Despres 2004).

13.2.1 Science Education Literature

The science education literature provides a rich source of ideas on how science can be taught in ways that relate to student lives and interests. Goodrum (2006), Goodrum et al. (2001), Rennie (2006) and Tytler (2007) have all pointed out the failure of many teachers of science to provide relevant and engaging science experiences for their students. It is emphasised in the literature that science courses must be situated, engaging and relevant, that is, connect to student life worlds and 'located in the multiple societal contexts within which citizens are involved – at home, in their neighbourhood, in their work, at leisure and as members of local, regional and national communities' (Fensham 2003, p. 8). This is further supported by Hodson (2003) who suggests the science curriculum be orientated towards socio-political action. In the curriculum and general study courses, the focus is to shift students' perceptions of science learning as being primarily about knowledge acquisition delivered using a transmissive style of pedagogy, an approach that Fensham (2003) suggests leads to a combination of low interest and too high a cognitive demand towards that which also focuses on political action. The first two principles for science education as outlined by Harlen (2010, pp. 6–8) resonate with the directions of the science curriculum courses, the first one stating 'Throughout the years of compulsory schooling, schools should, through their science education programmes, aim systematically to develop and sustain learners' curiosity about the world, enjoyment of scientific activity and understanding of how natural phenomena can be explained' and the second principle stating ‘The main purpose of science education should be to enable every individual to take an informed part in decisions, and to take appropriate actions, that affect their own wellbeing and the wellbeing of society and the environment’.

13.2.2 Education for Sustainability

Educating for sustainability (EfS) seeks to provide knowledge and understanding of the physical, biological and human world; the skills of critical argument; and the capacity and motivation to work towards harmony and sustainability through practical action. This approach involves students making decisions about ethical, social, cultural, environmental, gender, economic and health issues and acting upon them. Education for sustainability embodies the theory and practice of social, economic and ecological sustainability, and, in turn, ecologically sustainable development depends on sustainable education and learning (Sterling 2001). So, an important aspect of our practice is to encourage students to make a positive difference in their world and to live more sustainably as empathetic companions of all the Earth’s creatures and structures (Suzuki and McConnell 1997). We have drawn on the work of Jucker (2002), Sterling (2001) and local and national reports (ARIES 2009; DECS 2007; DEWHA 2010; Gough and Sharpley 2005; Steele 2010) in the area of education for sustainability and other sustainability advocates such as Capra (1996, 2002) and Lowe (2009 n.d.). Education for sustainability strongly informs the sequence of the science and mathematics courses and is the basis of many of the workshops. Four practical examples will be described in the next section.

13.2.3 Futures Thinking

Futures in education is considered by many educators (Beare and Slaughter 1993; Gough 1990; Gidley 2002; Hicks 2002; Page 1996) as being a neglected but essential dimension of education, essential primarily because ‘visions and views of desirable futures always come before their realisation. Yet today positive visions are in very short supply’ (Beare and Slaughter 1993, p. 105). The literature states that students should develop the skills and foresight to manage and instigate change within educational settings. It is argued that because learning is a life-long process and education is an integral component of constantly changing environments, images of futures affect powerfully what people believe and how they respond in the present. Bell (1998, p. 22) suggests that ‘one of the most important futurist purposes is the study of images of the future’, and Henderson (2002) states that ‘visioning exercises are necessary, pragmatic and can yield practical results’ (Henderson n.d). It follows that learning settings have a special responsibility to ensure that all members of a learning community are prepared for and proactive about their future (Lloyd 2005, 2007, 2010; Lloyd and Wallace 2004, 2006; Lloyd et al. 2010).

Whilst the science education literature does not explicitly point to futures education, the education for sustainability literature does (e.g. Ferreira et al. 2009; Tilbury and Cooke 2005; UNESCO 2005). Ehrlich and Ehrlich (in Orr 2010, p. 82) say that science has already shown the way towards a sustainable future by elucidating the problems and outlining many solutions. The challenge for education (school and community) is to figure out how to frame solutions in ways that will motivate people to respond; a facility integral futures thinking is designed to do so (Slaughter 2004). Developing of foresight is a task we have taken on in our courses, and students are given opportunities to reflect upon and develop positive images of possible futures.

13.2.4 Place-Based Education

Authentic education, as Sterling (2001) argues, has always been rooted in place and tradition. A necessary component of teacher education courses is that community living occurs in a diversity of settings and which 'connects education to locality' (Jucker 2002, p. 294). This place-based learning takes hands-on experiential learning, extending it beyond the classroom curriculum, and encourages students to be co-managers of their learning (Smith 2002; Woodhouse and Knapp 2000). Ideally, the result becomes a constructivist's idea of what education can best be: students responsible for their own learning and learning that takes place by 'doing' in authentic situations. Students do their learning by studying the place(s) they live, learn and play – places they are familiar with, perhaps taken for granted, and usually not closely scrutinised and studied. They are places they take responsibility for ethically and actively.

The primary value of place-based education is the way that it serves to strengthen children's connections to others and to the regions in which they live. The importance of connecting students to the natural world (Louv 2008; Sobel 2008) is a key aspect of place-based education. It serves both individuals and communities, helping individuals to experience what they value and hold for others and allowing communities to benefit from the commitment and contributions of their members (Woodhouse and Knapp 2000). In the fourth year, elective course students complete a placement in an urban ecological setting and work in a voluntary capacity, undertaking such tasks as revegetation and removing non-indigenous plants (Borgelt et al. 2009).

13.2.5 Transdisciplinary Education

Whilst the School of Education and the schools that it serves maintain a quite rigid silo curriculum structure made up of subjects or learning areas, we have, within the confines of imposed structures, started to explore interdisciplinary and transdisciplinary views of curriculum, teaching and learning. An interdisciplinary approach brings to the study of place a number of ways of knowing (science, mathematics, sociology, history, etc.). A transdisciplinary approach is about problem-solving where the understanding of relevant disciplines and local knowledge are used to resolve the issue or problem.

Often, science learning will contribute to the study of issues or topics that require an interdisciplinary or transdisciplinary approach. We are using interdisciplinarity to indicate that many disciplines are used in the study of a problem or theme (Wallace et al. 2005), and transdisciplinarity to refer to an approach that uses many disciplines *and* the grounded, local knowledge and needs of those in a particular social setting to approach a problem (Balsiger 2004; Després et al. 2004). Balsiger (2004, p. 407) states that transdisciplinarity is a scientific approach to understanding the world with a strong orientation towards societal problems.

The pressure to adopt transdisciplinary practices comes from the need to solve complex socio-scientific problems, where one discipline on its own cannot provide an answer (Bruce et al. 2004; Horlick-Jones and Sime 2004), and this is certainly an issue for education as a social process and for curriculum delivery in the learning setting.

Transdisciplinary thinking ensures that we look for and value the self, the social and the cultural in science learning and directs the selection of topics and their construction. We illustrate transdisciplinary learning later using a topic called *A place in time.*

Whilst we have not been able to take on all aspects of the literature we mention above, and to the degree that the authors suggest, we have been able to introduce our students to these ways of thinking and acting in the science/mathematics educational context. Our aim is to provide our students with ways of thinking about curriculum and pedagogy that will prepare them for future developments in school curriculum and pedagogical practices. Current thinking in the area of EfS certainly points to each of these areas as important for twenty-first-century education. We now provide an overview of the curriculum structure and examples to illustrate how the discussed literature has been incorporated into our courses.

13.3 Structure of the Curriculum

Over the last decade, a team of science and mathematics primary/middle educators have worked collaboratively to develop a cohesive suite of courses, some compulsory and others optional (Chartres et al. 2003; Lloyd and Paige 2008; Paige et al. 2005, 2008). The four compulsory curriculum courses involve a semester in each year of the programme. All courses are characterised by participation in interactive workshops rather than the traditional lecture tutorial model. The cohesive four-course sequence has two key themes: first, to develop pre-service teachers' science and mathematics conceptual understanding through different vehicles with a leaning towards educating towards ecological sustainability and, second, planning for learning which is where students plan and implement increasingly more complex tasks with students in their practicum placements.

The optional courses involve an elective general study sub-major in science, which we do not have space to elaborate upon here. A second optional course is taken in the fourth year where students select a learning area specialisation based on their general study option which leads to their final practicum placement. In our context, the students select a learning area specialisation in science and mathematics in either primary or middle school settings. Each year, we have between 8 and 16 students. This small number correlates with research done on the lack of background and confidence in science and mathematics that students bring with them to this programme (Paige et al. 2008).

Details of the science and mathematics vehicles which are covered at each year level in the compulsory courses and the optional science and mathematics learning area specialisation course are reported in the second column in Table 13.1. The third column identifies the key pedagogical foci for each course. The workshops provide an opportunity to explicitly model practices such as the different stages of the Interactive Teaching Sequence (Faire and Cosgrove 1993) and the 5 Es (Australian Academy of Science 2007). The fourth column describes the increased complexity of the science and mathematics tasks they plan, implement and evaluate in their school placements. It is the combination of the interactive workshops and connections with planning for learning in authentic places which develop the students' confidence to teach science and mathematics.

The structure of these science and mathematics courses has several features and subsequent benefits. First, each of the courses builds on the previous course so that over the 4 years students build their confidence to teach science and mathematics. They are not one-off, stand-alone courses but a sequence of coherent courses with each increasing in complexity as seen by Table 13.1.

In the first course, students are exploring the ideas of property and attribute through a series of practical workshops where natural objects such as rocks, feathers and shells are sorted and classified using both a science and mathematics way of knowing. They plan and present a prior knowledge experience with three children. In the second course, the students experience different vehicles, surface area and angle in mathematics and electrical circuits and soils in science, and plan three lessons to teach to their practicum class. In the third course, the content focuses on fractions and acid and bases and planning units of work to teach in their third practicum. The fourth-course students participate in a transdisciplinary workshop sequence which becomes the basis of a round-table assessment.

Second, the sequence provides an opportunity for the same staff to see the students more than once and hence develop relationships. Whilst there has been a reduction in staff, we have managed to maintain the cohesion through the dedication and commitment of both tenured and sessional staff. Staff work in combinations of curriculum courses, general study and practicum courses which support students to develop as generalist teachers in 3–7 classrooms and specialists in 8–9 classrooms.

Third, a major part of the integration is linked to the pedagogy. The way mathematics is learned is similar to the way science is learned. Our practice has been informed by a constructivist approach to teaching and learning, and building on the ideas through each of the courses ensures a high level of understanding for those students who engage (Skamp 2008; Van de Walle et al. 2010). Hence our commitment to interactive workshops rather than a lecture/tutorial model more common in universities.

Table 13.1 Overview of compulsory and optional science and mathematics courses

		Planning for learning
Content vehicles	Key pedagogical foci	Links to practicum
Studies in science and mathematics education 1 (1st year)		
Sorting and classifying	Understanding the disciplines of science and mathematics	Plan and implement a prior knowledge learning experience of a science and mathematics concept with three students and plan next lesson
Vertebrates and invertebrates	Introducing the Interactive Teaching Sequence/5 Es	
Pattern	Interdisciplinary approach	
Number	Key concepts, thinking and working	
Forces and movement		
Studies in science and mathematics education 2 (2nd year)		
Measurement (area)	Developing student's questions	Plan, implement and evaluate sequence of three lessons in both science and mathematics to teach in second practicum
Electrical circuits and energy use	Exploratory experiences and investigations to build on prior knowledge	
Spatial sense (properties of 2D figures)	Integration	
Soil science	Lesson-planning sequence	
Mathematics (3rd year)		
Chance	Unit planning	Plan, implement and evaluate a unit of work in science and mathematics in third practicum
Rational number		
Acids and bases		
Numeracy: issues in mathematics and science education (4th year)		
Dimensions of numeracy	Transdisciplinary workshop sequence *A place in time*	Round-table assessment
Mental computation	Sustainability	
Data handling		
Professional pathway (optional 4th year)		
Educating for sustainability	Transdisciplinary planning	Digital narrative
History and philosophy of science and mathematics	Planning for learning models: 5 Es, interactive teaching, critical praxis	Year planner in science and mathematics
	Place-based experience	

Interactive workshops provide an opportunity to model effective practice and develop deep learning. Workshops authentically link theory with practice, for example, interacting with manipulative material, engaging with online learning tools and spending time in the outdoors.

Fourth, links to practicum placements in their second, third and fourth year allow students to develop their confidence and competence to plan, teach and evaluate science and mathematics experiences in increasing complexity, from a prior knowledge activity with a small group of students in their first year to a transdisciplinary unit over a 5-week block in their fourth practicum. Four examples of how ecological sustainability leading to possible action is woven through the courses are the focus of the next section.

13.4 Putting Educating for Sustainability into Practice

Each of the four following examples provides an insight into how education for sustainability is translated into practice in the science and mathematics courses. The first two examples use an interdisciplinary approach using mathematical and scientific ways of knowing and primarily focus on science and mathematics conceptual learning; the second two examples use a transdisciplinary approach to solving problems which require mathematics and science understandings, in these cases, connecting students to community and place.

The first example occurs in the second year course where a series of three workshops focus on electrical circuits and energy use. In the first workshop, the students explore their prior knowledge of electrical circuits through annotated diagrams of torches and are provided with opportunities to develop their understandings of circuitry, currents, voltage, conductivity and electrical energy measurement. In the second workshop, the students are involved in investigating their own questions around parallel and series circuits, current and voltage. Students are exposed to a range of models for recording their investigations including those presented by Primary Connections (Australian Academy of Science 2007). In the third workshop, students are asked to bring in the wattage reading from an appliance that they commonly use such as a hair straightener and a microwave as well as a recent electricity bill. Students measure the amount of electrical energy they use for their appliance and then work out, using indirect measurement, their greenhouse emissions for that appliance for the billing period. This is a good example of how the sustainability focus is evident but the science and mathematics is still central and how a sustainability focus can be introduced into a science/mathematics unit.

The second example is a two-workshop sequence which focuses on exploring mathematics for citizenship through data handling. In the first workshop, the students explore ideas of mean, median and mode through collecting data about themselves, for example, their height and neck circumference, and representing it in a range of ways including using software packages such as *TinkerPlots*. In the second workshop, the students are asked to collect and bring data about their personal water consumption. For example, the amount of water to wash, amount of water flushed via toilet and amount of water consumed in washing/cleaning clothes, cars, home, dishes and personal items. The students use stem and leaf and box and whisker graphs to represent and compare aspects of the data. The workshop draws two conclusions: ways students can reduce their personal water use and ways that different countries use water, using data from the *New Internationalist* magazine and Anita Roddick's *Body Shop* website.

The third example occurs in the fourth year numeracy: issues in science and mathematics course, focusing on a transdisciplinary topic, *A place in time*. Building on science and mathematics concepts covered in previous years, pairs of students select a significant tree on campus, and using three different lenses, (science, mathematics and sustainability) they connect to a place on campus. Using the mathematics of measurement, they explore the attributes of distance, surface area and capacity. For example, they develop strategies to estimate the heights of the tree, the number of leaves and the area of the tree's shadow throughout the day. They also describe its location using distance and direction and construct a map so others can locate it. Using a science lens, they investigate the properties of soil such as colour, pH levels and porosity. They identify the physical structures of the tree and its functions, the animals living in or near it and why they live there. They also collect data about aspects of weather (e.g. temperature, humidity and cloud cover) at different times of the day. Next, using a sustainability lens, students construct a futures scenario of their place in 50 years time and use Van Matre (1990) sensory activities to add to their sense of place. There is a requirement that they talk about undertaking a possible action, for example, planting sedges to attract butterflies to the campus. A summative assessment involves students presenting their findings at a round table (Australian National Schools Network 2002). This example involves students thinking and working mathematically, scientifically and sustainably outside the classroom. Engaging with students' local environment to develop a sense of place and connection are two of the teaching pedagogical practices embedded in this topic (Paige et al. 2008).

The fourth example occurs in the professional pathway which is held in the semester before their final practicum. Ecological sustainability is a key focus. The course consists of two components. The first component focuses on planning and programming where students plan a unit of work in science and a unit of work in mathematics and present this as a professional development experience to their peers together with a transdisciplinary unit of work for a nominated level of schooling. The second component focuses on a place-based experience which is assessed through the presentation of a digital narrative. In the place-based experience, students spend time in an urban ecological setting, undertaking such tasks as removing non-indigenous plants from national parks and collecting data about water quality in local rivers. This voluntary work over the semester results in pre-service teachers adding to their knowledge of ecological science, developing a sense of belonging with a community, connecting to a new place and developing an appreciation for the needs of future generations.

The four examples provide an outline of how ecological sustainability is woven through the courses spread over the 4 years. The science and mathematics is still central but it is covered within a context that is relevant for student life worlds. It is expected that these experiences will provide the pre-service educators with the confidence to implement meaningful and rigorous science and mathematics during their practicum, in the first instance, but later as beginning teachers. The next section explores feedback from students who have undertaken these courses.

13.5 Evaluation of Student Data

What impact does participating in the courses have on developing pre-service teachers' confidence to teach science? At the end of each semester, students are invited to complete an online course evaluation. In this study, we focus on feedback from three of the five courses, the first and second year compulsory courses we use the course evaluations as the main source of data. The third course included is the optional fourth year course which has low numbers and therefore provides an opportunity for in-depth focus group discussions and explains the difference in evaluation data. These three courses are well established and have been refined over several years. The other two courses are still undergoing development and modification.

13.5.1 Science and Mathematics Education 1 (1st Year Course)

Examining the 2008 data for the first year course provides some useful insights. Of the 143 students who took part, 58 (41%) completed the survey. For the question, 'Overall I was satisfied with the quality of this course', 71% either agreed or strongly agreed. Only 9% replied in the negative. Two other questions relevant here were asked: (1) What are the strengths of the course? (2) What ways has this course supported you to develop confidence to teach science and mathematics?

Comments about the strength of the course have been organised around the themes of pedagogy, building content knowledge, learning theory, resources and assessment. The proportion of responses from the pre-service teachers has been recorded as a percentage after each theme.

Pedagogy (34%)

Recurring themes about pedagogy include the hands-on approach to learning, modelling good practice, having the opportunity to put ideas into practice and resources. A sample of responses that refer to pedagogy are listed next:

> The 'hands-on' approach to learning, for example, the structured play time, was very helpful.
> Being active in manipulating materials and 'getting your hands dirty' to better understand concepts.
> How the tutor models the constructivist strategies we are required to learn.
> Use engagement activities, proved very successful!
> The many different techniques of constructivist teaching and how the teacher exhibited them.
> Having an opportunity to put some things into practice by conducting the prior knowledge activities with learners.
> It explored how to construct a learning experience which will help with future teaching.

Resources (22%)

A second key theme to emerge from the survey was about the importance of resources. Two typical responses that reflect pre-service views include:

> The course has highlighted some good resources to assist in teaching science and maths.
> Provided endless ideas of how to approach lessons and activities for the students to participate in.

The remaining three themes include content knowledge, learning theory and assessment and are encapsulated in the following responses.

Content knowledge (19%)

Providing a good basic understanding of some key mathematical and science concepts
The relevance of content to what we will be teaching in schools

Learning theory (9%)

How it makes you understand how children learn maths and science concepts
Learnt how to become a constructivist teacher

Assessment (8%)

The assignments were practical tasks which we will eventually use in our teaching careers.
I believed a strength was the assignments where we were able to interact with students and were able to get an understanding of their learning and enjoyment.

Overwhelmingly, this group of students found this course of value for its hands-on approach, the modelling of constructivist practices and the opportunity to put theory into practice during their practicum placement. A few students found the workshop approach unhelpful, preferring a lecture style approach, and a few students said they needed extra help to understand the assignment tasks. Interestingly, there were no comments on aspects of sustainability modelled in the workshops.

13.5.2 Science and Mathematics Education 2 (2nd Year Course)

For this course, comments about ways the course has supported students to teach science and mathematics have been organised around three themes that emerged during the analysis of their course evaluation: confidence, inspiration and engagement. The percentage of responses that reflect each theme is recorded after the heading. Examples of answers to the question ‘What ways has this course supported you to develop confidence to teach science and mathematics?’ include:

Confidence (28%)

It has made me realise it’s not that hard after all.
The assignments on creating lesson plans and understanding prior knowledge has given me a confidence boost.
Made me realise how exciting science and maths can be when it is taught in such an engaging, manipulative, active and relevant way.
This course gave me the confidence to teach mathematics and science in my practicum; my mentor noted on my report, my passion, for my science teaching.

Inspiration (21%)

The enthusiastic teachers and useful information.

How we cover what is needed by you as the teacher as well gives us clear knowledge of what is expected of us in the future.
I thought science and mathematics would be two boring subjects to teach; however, the course has shown me fun ways to approach these subjects.

Engagement (16%)

The ways in which we learnt, new things they were always interesting.
High-demand subject.
One of the main elements that this course taught was to always find out the 'before views' of the students before proceeding with a lesson plan.
To go the extra length to actively participate in workshop discussions.

Examining the 2008 data for the second compulsory course also provides some useful insights. These students seem to be more confident in providing critical comments. Of the 115 students who took the second course, 35 (30%) completed the survey. For the question 'Overall I was satisfied with the quality of this course', 80% either agreed or strongly agreed. Only three students (8%) replied in the negative. This course is connected with students' second practicum experience in which they are required to plan and teach units of work. What students found of particular value with this second course was the way it prepared them for teaching in their practicum placement. Particular aspects they refer to include planning for learning, knowing the importance of and how to elicit students' prior knowledge. One student commented with respect to this aspect, 'Not having a sound background or confidence in either learning areas I surprised myself and my ability to teach in these areas'.

13.5.3 Professional Pathway in Mathematics and/or Science

In their fourth year, students choose a specialisation pathway which is connected to their final practicum. In 2010, 15 of the 16 science/mathematics pathway students completed a questionnaire on the value of the course. Most students mentioned the importance of maths/science learning for living an informed life. For example, one student said that mathematics and science 'are important subjects, maths and science are in everyday life, and if you want to develop successful citizens maths and science will (help) do this'. Students also described how this final course in their preparation for teaching had 'built up … confidence to teach effectively'. But what was most pleasing was that many identified the joy and pleasure that can come from studying these subjects provided they are taught in an interactive and engaging way; 'There are so many ways to teach these learning areas in an engaging and rewarding way; What is important is to engage students with experiences that are relevant to their lives'. They saw the value of 'place-based experiences in connecting to the community' and the 'photo stories provided an idea on what groups/organisations can be incorporated into student learning'. Students indicated that they had 'Built confidence as an educator with diverse and specific teaching strategies/skills that can be used across the curriculum' and the course had 'strengthened … skills in planning units and made me more specific in what I'd want to teach and how students learn best'.

When reflecting back over the 4 years about their understanding and practices of sustainability, one student responded:

> The overall impact of the courses has changed my world view and impacted on many of the decisions I make about my personal life. I think that I will be able to share this with my future students and this is an area that I feel is very important and perhaps where I can make one of my biggest contributions for future societies. I hope that my future students will learn to question and inquire scientifically and use the thinking and working skills from the mathematical and scientific concepts that they learn in my classrooms to help them decide on their future and also make a difference to future generations. It has been a fantastic learning journey!

13.6 Key Findings

What can be drawn from this evaluative data? What can be said about the key themes that have underpinned our coherent sequence of courses, place-based education, transdisciplinary education, futures thinking and educating for sustainability? What have we learnt about how pre-service primary/middle teachers have been influenced by these themes? Reflecting on these questions indicates that whilst we have a strong theoretical framework for our course construction, we are only in the beginning stages of ascertaining the impact on pre-service teachers' confidence to teach science. The innovative approach to teaching science curriculum involves an enormous amount of intellectual work as individuals and as a team. At the end of workshops, assignment moderation and semester's work, we are looking for ways to do things better. Feedback from students via the course evaluation instrument provides a student perspective. However, the questions are set, and whilst we can add our own, it adds to the length of the survey and reduces students responses. So, whilst we have some initial data, it highlights the need to do more comprehensive evaluation to provide deep analysis of all key themes. At this stage, we can really make comment about two key themes: educating for sustainability and the lack of it in the first two courses and place-based education in the fourth year course.

Feedback indicates that pre-service teachers are developing their confidence to teach science and mathematics. The approach modelled in interactive workshops actively engages students in constructing their conceptual understanding. Comments reflect the positive impact this has on their learning and confidence to teach in these two areas.

It appears that the first two courses are coherent, that the students can see each course builds on the previous and that the passion and inspiration of the teacher is crucial. Second, the links with practicum in their second course enables the students to practise their planning for learning within an authentic context. Students acknowledge how much they appreciate being scaffolded within the assessment framework to construct lesson plans which are transferrable into the classroom.

What is evident from the evaluation from these two courses is the lack of comments referring to the impact of the focus of educating for sustainability. It appears in the first 2 years that students are in 'survival' mode and need to start with developing conceptual understanding in each learning area and foundations in how to teach before planning within an interdisciplinary framework that has sustainability themes. However, by the fourth year, pre-service teachers enrolled in the science and mathematics pathway, though still focusing on the importance of taking the final step towards teaching independently in terms of preparation as a beginning teacher, were in a position to take on board the complexities of educating for sustainability and place-based education. Planning transdisciplinary topics for their final practicum contextualised the science around topics such as sustainable energy, water conservation and kitchen gardens. This was evident by the students being able to 'walk the talk', that is, incorporate the principles of educating for sustainability in their planning. In a different way, their experience with place-based education had been influential. Undertaking the place-based experience had contributed to their confidence to work in a voluntary capacity, developing connectivity to community. Whilst they acknowledged the impact of this on their own learning, it was not easy to implement when undertaking a 5-week final placement. Investigating this with recently graduating teachers would provide further insights.

In summary, the opportunity to reflect on the impact of the spiral curriculum over the 4 years highlights the pre-service teachers' improved confidence to plan, implement and evaluate science and mathematics; only in their fourth year were they able to make connections between pedagogy and educating for sustainability. Building on this feedback, and exploring other themes such as futures thinking and transdisciplinarity, more explicitly needs to be the basis of future research.

13.7 Concluding Comments

We have used evidence from students' course evaluations to continuously improve an approach to teaching science and mathematics which attempts to balance traditional pedagogical content knowledge with the emerging need to far more strongly connect curriculum to student life worlds and the emerging issues around sustainability. Such an approach takes science knowledge beyond the technical to include personal well-being, ethical living and the political action as suggested by Fensham (2003), Hodson (2003) and Tytler (2007). We use the content knowledge as vehicles to illustrate effective teaching practice so that students can experience what their students will experience and, as educators, reflect upon the value/effectiveness of our approach. The learning experiences are interactive, place based and situated in an explicitly identified integral space.

Our approach is evolving. The introduction of a fourth year course which uses issues as the vehicle to develop science and mathematics concepts and processes is an example of the ongoing development. The issues will be local as well as global, focussed upon ecological sustainability and transition to a low-carbon society and develop ideas of intra- and intergenerational equity. This course, along with the others in the programme, will complement the School of Education's focus on reducing its ecological footprint and developing confident, well-informed, futures-thinking 'green' teachers.

Our challenges will be with our own ability to learn and adapt in a rapidly changing and globalising world and to do so within the resource limits placed upon us by the university administration.

References

ARIES. (2009). *Education for sustainability: The role of education in engaging and equipping people for change*. http://www.aries.mq.edu.au/publications.htm. Accessed 19 Aug 2009.

Australian Academy of Science. (2007). *Primary connections: Linking science with literacy*. http://www.science.org.au/primaryconnections/index.htm. Accessed 14 Oct 2009.

Australian National Schools Network. (2002). *Assessment by exhibition*. Sydney: Faculty of Education.

Balsiger, P. W. (2004). Supradisciplinary research practices: History, objectives and rationale. *Futures, 36*, 407–421.

Beare, H., & Slaughter, R. (1993). *Education for the twenty-first century*. London: Routledge.

Bell, W. (1998). Understanding the futures field. In D. Hicks & R. Slaughter (Eds.), *Futures education* (pp. 15–26). London: Kogan Page.

Borgelt, I., Brooks, K., Innes, J., Seelander, A., & Paige, K. (2009). Using digital narratives to communicate about place based experiences in science. *Teaching Science, 55*(1), 41–46.

Bruce, A., Lyall, C., Tait, J., & Williams, R. (2004). Interdisciplinary integration in Europe: The case of the Fifth Framework programme. *Futures, 36*(4), 457–470.

Capra, F. (1996). *The web of life: A new synthesis of the mind and matter*. London: Flamingo.

Capra, F. (2002). *The hidden connection: Integrating the biological, cognitive, and social dimensions of life into a science of sustainability*. London: Flamingo.

Chartres, M., Lloyd, D., & Paige, K. (2003). Integrating science and mathematics in an undergraduate teacher education program. In D. Fisher & T. Nash (Eds.), *Third international conference on science, mathematics and technology education* (Vol. 2, pp. 561–567). East London: Key Centre for Science and Mathematics, Curtin University of Technology, Perth, Australia.

DECS. (2007). *Education for sustainability: A guide to becoming a sustainable school*. Adelaide: Department of Education and Children's Services.

Després, C., Brais, N., & Avellan, S. (2004). Collaborative planning for retrofitting suburbs: Transdisciplinarity and intersubjectivity in action. *Futures, 36*(4), 471–486.

DEWHA. (2010). *Sustainability curriculum framework: A guide for curriculum developers and policy makers*. Canberra: Commonwealth of Australia.

Faire, J., & Cosgrove, M. (1993). *Teaching primary science*. Hamilton: Waikato Education Centre.

Fensham, P. J. (2003). What do the 'All' need in science education? In D. Fisher & T. Marsh (Eds.), *Third conference on science, mathematics and technology education* (pp. 1–20). East London: Key Centre for School Science and Mathematics, Curtin University of Technology, Perth, Australia.

Ferreira, J.-A., Ryan, L., Davis, J., Cavanagh, M., & Thomas, J. (2009). *Mainstreaming sustainability into pre-service teacher education in Australia*. Canberra: Australian Research Institute in Education for Sustainability, Graduate School of the Environment, Macquarie University.

Gidley, J. (2002). Global youth culture: A transdisciplinary perspective. In J. Gidley & S. Inayatulla (Eds.), *Youth futures: Comparative research and transformative visions* (pp. 3–18). Westport: Praeger.

Goodrum, D. (2006). *Inquiry in science classrooms: Rhetoric or reality?* http://www.acer.edu.au/research_conferences/2006.html. Accessed 27 Nov 2007.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools*. Canberra: Department of Education, Training and Youth Affairs.

Gough, N. (1990). Futures in Australian education: Tacit, token and taken for granted. *Futures, 22*(3), 298–310.

Gough, A., & Sharpley, B. (2005). *Educating for a sustainable future: A national environmental education statement for Australian schools*. http://www.environment.gov.au/education/publications/pubs/sustainable-future.pdf. Accessed 19 Aug 2009.

Gruenewald, D. A. (2003). The best of both worlds: A critical pedagogy of place. *Educational Researcher, 32*(4), 3–12.

Harlen, W. (2010). *Principles and big ideas of science education.* Report from International Seminar of Science Educators, October 2009, Scotland.

Henderson, H. (n.d). *Education for the Third Millennium: Looking back from 2050*. http://www.newhorizons.org/future/hendersonh.htm. Accessed 7 Mar 2006.

Hicks, D. (2002). *Lessons for the future: The missing dimension in education*. London: Routledge.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*(6), 645–670.

Horlick-Jones, T., & Sime, J. (2004). Living on the border: Knowledge, risk and transdisciplinarity. *Futures, 36*(4), 407–421.

Jones, P., Selby, D., & Sterling, S. (Eds.). (2010). *Sustainability education: Perspectives and practice across higher education*. London: Earthscan.

Jucker, R. (2002). *Our common illiteracy: Education as if the Earth and people mattered*. Frankfurt: Peter Lang.

Lawrence, R. J., & Despres, C. (2004). Futures of transdisciplinarity. *Futures, 36*(4), 397–405.

Lloyd, D. (2005). *Educating for the 21st Century: Planning a teacher education program for primary and middle schooling* [electronic version]. http://www.aaee.org.au/docs/2004conference/Lloyd%20D.doc

Lloyd, D. (2007). Exploring students' futures images. In P. C. Taylor & J. Wallace (Eds.), *Contemporary qualitative research: Exemplars for science and mathematics education* (pp. 57–66). Dordrecht: Springer.

Lloyd, D. (2010). Futures scenario construction around contemporary issues: Tertiary students' perceptions of their value. *The International Journal of Environmental, Cultural, Economic and Social Sustainability, 6*(4), 85–106.

Lloyd, D., & Paige, K. (2008). Valued science and mathematics learning in middle schooling: Connecting to students' lived experiences. In D. Fisher, R. Koul, & S. Wanpen (Eds.), *Fifth international conference on science mathematics and technology education* (pp. 334–347). Udon Thani: Rajabhat University, Key Centre for School Science & Mathematics, Curtin University of Technology.

Lloyd, D., & Wallace, J. (2004). Imaging the future of science education: The case for making futures studies explicit in student learning. *Studies in Science Education, 40*, 139–178.

Lloyd, D., & Wallace, J. (2006). Futures studies and science education. *The Science Education Review, 5*(1), 6–8.

Lloyd, D., Vanderhout, A., Lloyd, L., & Atkins, D. (2010). Futures scenarios in science learning. *Science Teaching, 56*(2), 18–23.

Loeb. (2001, July/August). Teaching for engagement. *Academe 2001.*

Louv, R. (2008). *Last child in the woods: Saving our children from nature-deficit disorder* (2nd ed.). Chapel Hill: Algonquin Books.

Lowe, I. (2009). *A big fix: Radical solutions for Australia's environmental crisis* (2nd ed.). Melbourne: Black Inc.

Lowe, I. (n.d.). *The need for environment literacy* [electronic version]. http://www.staff.vu.edu.au/alnarc/onlineforum/AL_pap_lowe.htm. Accessed Jan 2009.

Matre, V. (1990). *Earth education: A new beginning*. Warrenville: Institute of Earth Education.

Orr, D. (2010). What is higher education for now? In L. Starke & L. Nastny (Eds.), *State of the world 2010: Transforming cultures from consumerism to sustainability* (pp. 75–82). London: Earthscan.

Page, J. (1996). Education systems as agents of change: An overview of futures education. In R. A. Slaughter (Ed.), *New thinking for a new millennium* (pp. 126–136). London: Routledge.

Paige, K., Lloyd, D., & Chartres, M. (2005). The next step: Moving from integrating mathematics and science to incorporating educating for ecological sustainability for primary/middle years students. In D. Fisher, D. Zandvliet, I. Gaynor, & R. Koul (Eds.), *Third international science, mathematics and technology conference*. Victoria, Canada.

Paige, K., Lloyd, D., & Chartres, M. (2008). Moving towards transdisciplinarity: An ecological sustainable focus for science and mathematics pre-service education in the primary/middle years. *Asia-Pacific Journal of Teacher Education, 36*(1), 19–33.

Rennie, L. (2006). *The community's contribution to science learning: Making it count*. http://www.acer.edu.au/documents/RC2006_Rennie.pdf. Accessed 23 Sept 2006.

Skamp, K. (Ed.). (2008). *Teaching primary science constructively* (3rd ed.). Southbank: Thompson.

Slaughter, R. A. (2004). *Futures beyond dystopia: Creating social foresight*. London: Routledge.

Smith, G. A. (2002). Place-based education: Learning to be where we are. *Phi Delta Kappan, 83*(8), 584–594.

Sobel, D. (2008). *Children and nature: Design principles*. Portland: Stenhouse.

Steele, F. (2010). *Mainstreaming education for sustainability in pre-service teacher education: Enablers and constraints*. Australian Research Institute in Education for Sustainability.

Sterling, S. R. (2001). *Sustainable education: Re-visioning learning and change*. Totnes: Green Books for The Schumacher Society.

Suzuki, D., & McConnell, A. (1997). *The sacred balance: Rediscovering our place in nature*. St Leonards: Allen & Unwin.

Tilbury, D., & Cooke, K. (2005). *A national review of environmental education and its contribution to sustainability in Australia: frameworks for sustainability – Key findings*. Canberra: Government Department of the Environment and Heritage and Australian Research Institute in Education for Sustainability (ARIES).

Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Camberwell: ACER Press.

UNESCO. (2005). *United Nations decade of education for sustainable development (2005–2014): International implementation scheme*.

University of South Australia. (2010). *Primary middle program*. http://www.unisanet.unisa.edu.au/programs/program.asp?Program=LBPM&Year=2010. Accessed 27 Aug 2010.

Van de Walle, J., Karp, K., & Bay-Williams, J. (2010). *Elementary and middle school mathematics: Teaching developmentally* (7th ed.). New York: Pearson.

Wallace, J., Venville, G., & Rennie, L. J. (2005). Integrating the curriculum. In D. Pendergast & N. Bahr (Eds.), *Teaching middle years* (pp. 149–163). Crows Nest: Allen & Unwin.

Woodhouse, J., & Knapp, C. (2000). Place-based curriculum and instruction: outdoor and environmental education approaches. *Eric Digest*. http://www.ericdigests.org/2001-3/place.htm

Chapter 14
Using Simulations in Science: An Exploration of Pupil Behaviour

Susan Rodrigues

14.1 Introduction

Understanding chemistry, with or without information communication technologies (ICT), poses several distinctive challenges. For example, the learner has to engage with the abstract, often microscopic nature of the subject, in order to interpret concrete reactions, often depicted through macroscopic everyday situations, and then represent these interactions in the form of symbolic notation. Not surprisingly, teachers have relied on teaching aids to help them address these challenges. Over the last few decades, one of these teaching aids has come to include ICT incorporating various multimedia.

Mayer et al. (2003) define multimedia learning as the use of at least two different types of media (graphics, audio, video, text) in presenting information. In my view, multimedia forms of ICT have gained a foothold in chemistry education, primarily it could be argued, because the multimedia technology affords an opportunity to better visualize the relationships between the microscopic, macroscopic and symbolic levels of chemistry. However, it can also be argued that the use of multimedia enables a more dynamic approach in chemistry classroom teaching and learning. So, whereas in the past teachers of chemistry may have relied on ball and stick models, now three-dimensional animated visualization tools for subatomic matter is used to illustrate particular facets. For example, animated visualization tools are used to illustrate chemical reaction mechanisms in a more dynamic way (Ng 2010).

The dynamic potential of three-dimensional visualization tools is not the sole reason for promoting animations and simulations. Technology use in science lessons advances work production by relieving students from laborious manual processes while generating more accurate and reliable data (Rogers and Finlayson 2003).

S. Rodrigues (✉)
Northumbria University, Newcastle, England, UK
e-mail: susan.rodrigues@northumbria.ac.uk

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_14,

Where in the past students may have had to repeat time-consuming and sometimes tedious wet lab experiments, now it is argued ICT speeds up the process and results in the generation of reliable data. Indeed, Wardle (2004) suggests that the technology provides repeatable interaction and provides instant visual feedback. Trindade et al. (2002) suggest three-dimensional virtual environments help students, with high spatial aptitude, to acquire better understanding of particular concepts. Eilks et al. (2010) posit that informed software that allows for seamless interchange between tables, charts, graph and model display has the potential to support conceptual linking between these representations.

In addition to the body of literature identifying and documenting the dynamic potential of animations and simulations in chemistry lessons, the literature also reports on studies that identified the potential of ICT to motivate students. There is plenty of evidence to suggest that technology use in classrooms improves motivation and engagement, resulting in ongoing participation (Deaney et al. 2003; Koeber 2005). Given this body of evidence (see Barton 2002, 2004; Rodrigues 2010), it is easy to understand why ICT has found its way into mainstream chemistry classroom use. Furthermore, the potential of simulation-based technology to support the development of an ability to make informed connections between the macroscopic, microscopic and symbolic levels of chemistry has probably also resulted in increasing simulation deployment in chemistry classroom practices.

However, in tandem with the literature identifying potential opportunities and strengths, other literature identifies issues and challenges. For example, some suggested that the requirement for a high transfer rate may result in a limited attention span (Ploetzner et al. 2008). Another example of an issue can be seen where Testa et al. (2002) suggested that real-time graphs produce 'background noise' and are not 'cleaned' of superfluous details/irregularities, which may make these real-time graphs difficult to interpret. It was suggested that picture use in multimedia learning processes may not be beneficial in every case (Schnotz and Bannert 2003), and according to Schwartz et al. (2004) and Azevedo (2004), the use of non-linear learning environments may result in inadequate meta-cognitive competencies. Eilks et al. (2010) state that illustrations must be scientifically reliable, and they should take care not to encourage the development of incorrect or conflicting explanations. Most of us assume these two aspects (scientifically reliable and not encouraging the development of alternative explanations) are obvious, and yet research (see Hill 1988) has shown that even static illustrations, often found in school textbooks, fail to meet these two criteria.

Obviously, therefore, it is important for education software designers to consider research findings relating to learning and pedagogy when designing software intended to be used within classrooms. Designers' theories and views of learners and the assumptions designers make mean that content and pedagogy are intertwined well before they get into a classroom (Segall 2004). In essence, the manner in which a simulation has been designed and packaged is influenced by that design team's views of learning theories, processes and practices. The assumptions that design teams made with regard to how their software would or could be used may not be realized if the simulation is used by teachers and students with different views of learning theories, processes and practices, and in environments that do not support the design team's views of those elements.

The influence of ICT on student motivation has also been a strong driver in educational circles, but the literature also signals a difference in student interest levels in formal ICT-influenced environments in comparison with interest levels in informal ICT-influenced environments. Unfortunately, although learning through doing simulations or games has scope to provide powerful learning tools, the attempts to replicate levels of engagement and challenge found in games' design have met with limited success in the classroom.

Many pupils consider games developed for school use to be pseudo games perhaps because they are repetitive, simplistic and poorly designed or because the range of activity is limited (Kirriemuir and McFarlane 2004). Not surprisingly, discerning students, with experience of computer games, view educational games as limited. Kirriemuir and McFarlane (2004) suggest that instead of trying to replicate computer games for the education context, more should be done to understand the game experience and that should be used to design environments that support learning.

Not surprisingly, over the last couple of decades, research has reported on the influence of particular design elements on engagement and learning. For example, Clarke and Mayer (2003) reported a modality principle and posited that graphical information explained by onscreen text and audio narration led to cognitive overload and was therefore detrimental to learning. Others, like Ginns (2005) and Moreno (2006), substantiated this modality principle. But in more recent times, studies are emerging that suggest there is no difference in performance based on the presence or absence of audio narration (see Sanchez and Garcia-Rodicio 2008). The discrepancy in evidence (i.e. audio narrative augmenting or diminishing performance) has often been explained by two theories.

Paivios' dual coding theory (2006) premise is that multiple references to information with connections between the verbal and non-verbal (imagery) processing result in an improvement in the learning process. In contrast, Chandler and Sweller's (1991, 1992) idea regarding what has often been called the 'split attention' effect (learner addressing multiple information sources before trying to integrate the segments to make them intelligible), and their idea regarding what is termed 'redundancy' suggests that disparate sources may generate cognitive overload. Though the explanations provided by Paivios (2006) and by Chandler and Sweller (1991, 1992) may appear to be contradictory, they all make sense. As a result, the jury is still out as to which explanation has more currency.

So, informed by these conflicting views and the ongoing debate regarding simulation design issues, years ago in collaboration with others, I began investigating facets of simulation design. I analysed subject matter representations commonly found in simulations, and I considered the impact of these representations on user patterns of behaviour.

In this chapter, I present findings from a series of related but independent studies within this ongoing venture investigating the relationship between patterns of student behaviour and the design aspects of some chemistry simulations designed to support learning of school/college-based chemistry. I present these studies as stand-alone snapshots of the projects because the projects involved different teams, used unrelated samples, employed different methods and procedures and adopted a variety of new analytical frameworks. The studies are presented in terms of case study methodology and findings before I go on to present conclusions based on a collective of findings drawn from these various case studies. To maintain anonymity, names that appear in the chapter are pseudonyms, and sometimes I simply refer to their identification number or initials. At the end of the transcripts, there are codes that allow me to identify the source of the transcript.

14.2 Study A: Periodic Table CD-ROM and Student Engagement

Digital literacy includes the ability to use application software tools in a fashion that enables the user to perform and accomplish specific tasks (Ng 2010). In study A, together with some colleagues I explored factors likely to influence the development of this notion of digital literacy. Study A was conducted in Australia and involved one, girls-only, class. We introduced an European multimedia award-winning CD-ROM on the periodic table to this class. We asked the teacher to make this CD-ROM available on an individual basis for at least 20 min, at least twice a week. The CD-ROM began with an introductory screen, which presented the girls with three options. They could click on a button entitled periodic table, a button entitled elements or a button entitled quiz. The periodic table button took the girls to a screenshot of the standard periodic table, which was interactive in the sense that they could then select elements to review or consider patterns within the table. The element table allowed them to key in the name of an element, and a screen containing data pertaining to that element would then appear. The quiz button basically provided a screen with a further three options: 5-min quiz, 90-s quiz or sudden death quiz.

Data collection in study A was fairly traditional in the sense that it included surveys, interviews and observation. The girls' engagement with the CD-ROM was videotaped and analysed, and they completed pre- and post-activity questionnaires, which included basic questions about the periodic table. The analysis of the data was also fairly traditional in that it used a grounded theory approach. Fuller project details can be found in Rodrigues (2003).

The analysis showed that the extent of commitment and purpose appeared to be determined by the students' perception of the required outcomes. The students ignored the 'periodic table' and 'elements' buttons and opted for the 'quiz'. Once on the quiz screen, they ignored the '5-min' and '90-s' quiz options and chose the 'sudden death' quiz. At the end of their access period, they were keen to engage in dialogue with their peers in order to compare their scores. There was no notable change in their understanding of the chemistry of the periodic table. Students navigated a safe and repeatable route and did not have a favourable disposition towards risk taking and inquiry. In terms of findings, what we learnt from this project was that when given free access, there was a fairly standard pattern of behaviour. Given these findings, I worked with four software designers to produce another CD-ROM on the periodic table, and the issues, challenges and outcomes regarding that development process can be read in Rodrigues (2000). But in essence, the process highlighted the fact that while a conversation appeared to be shared between the developers and researcher, in reality the interpretation of particular language differed significantly. Hence, for example, constructivist terms were interpreted in terms of hands-on construction. While the Rodrigues (2000) project adds to the literature reporting on issues to do with system design, Barker (2008) describes models calculated to assist designers when they design multimedia products for school use.

14.3 Study B: Comparing Video and Simulations With and Without Text Explanations

Study B involved collaboration between Mary Ainley, a psychologist who was interested in the concept of ‘interest’ in science education, and me (a science educator interested in simulation design features). The project we developed was also the start of a change in the type of research methodology I would use to explore simulation use in chemistry. Up until this point, my projects had relied on interviewing simulation users after observing them or asking them to complete surveys after they used simulations.

In study B, we used a mechanism that allowed us to track the user pathways and generate records for their choices when given options. When users logged on, they were presented with a screen welcoming them and familiarizing them with the process. They supplied information about gender, age, experience and interests. They completed another screen that asked them some basic chemistry questions about the states of matter. They were then presented with preview screens before they selected a particular option, and they were asked to indicate their perceived level of interest in the given preview. In essence, they had four options: option 1 – a short video clip; option 2 – a video clip and text that explained the video clip; option 3 – a simulation; and option 4 – a simulation and the text explanation.

The user could opt out at any time. Then they completed an online post-survey and an online post-chemistry test. They could also review all four options or view one or any combination before proceeding to the next cohort of four options. In reality, the video clips showed mundane events (ice cubes melting or water boiling), and the simulations depicted these events on a microscopic level. Their choices were logged by the computer. Hence, while we did not observe them (in an intrusive manner by sitting within the vicinity), we were in effect observing their behaviour by tracking their choice patterns.

The use of this custom-designed package allowed us to track 11 Australian male and 11 Australian female students’ engagement as they explored and used animation and video clips with or without accompanying text and on the topics of dissolving, melting and boiling (fuller project details can be found in Rodrigues et al. 2001). Students said they selected their own route through the programme.

However, the tracks showed that 16 of the 22 students followed the prescribed sequential presentation route. Given the ordinariness of the video footage, it was notable that these 11- to 13-year-old students preferred viewing video clips rather than animations. The number of students viewing animations declined between selecting topic 1 and topic 2, and seven students never selected the microscopic level animations. Fifteen students cited ‘video and text’ as the most helpful presentation type to understand the science concepts. There was a marked increase in the use of text explanations between students selecting their first topic and their second topic. Most students selected topics because they were interested in them, but they selected presentation styles because of their perceived functionality and utility.

14.4 Study C: Observing Student Engagement with Simulations

In study C, student volunteers aged between 14 and 15 years from two schools in Scotland were digitally video recorded while using various online chemistry-based simulations. The students were given 5 mins to use (restart, repeat or review were possibilities) two randomly allocated simulations, which in most cases lasted less than a minute. As they used the simulation, a camera located just behind their shoulder recorded the screen activity and any talk between the students. These digital records were replayed to them, and their retrospective accounts were sought via a semi-structured retrospective interview technique.

There were two cohorts involved in this study. In one cohort, the digital records were obtained when individual students worked with the simulation. In the second cohort, the students worked in pairs. There were two reasons for the pair or individual option. Convenience was an instrumental factor (in terms of access to hardware), and this influenced whether students worked in pairs or individually. In addition, we were interested in seeing whether pupils would discuss aloud their potential actions when working in pairs. We felt this might help and provide a means to access pupil thinking at the time. Almost as soon as the students finished using two randomly allocated simulations, the digital records were played back to them. The students were asked to view the digital records and were then asked to explain their actions. These explanations were also recorded and transcribed later. Further details for this project can be found in Rodrigues (2007).

Unlike the previous two studies, in this case I used conversation/discourse analysis to guide data analysis, as the focus was on interactions and procedures as they emerged. This project was really an attempt to find out why particular decisions were made (rather than only what decisions were made). A best-fit heuristic method (Hutchby and Wooffitt 1998) was possible because of the sample size of 21 volunteers. This allowed for a review of all transcripts.

An initial analysis of Study C identified several design factors that influenced student engagement. These were prior knowledge, distraction (redundant segments) and vividness (items that stand out), logic and instructions. Secondary analysis of the transcripts also showed what I have chosen to describe as:

- Selective amnesia (seen but quickly forgotten).
- Attention capture (a function of redundancy, vividness, prior knowledge and instruction design).
- Inattentional blindness (missing items when engrossed). Inattentional blindness refers to an experience where someone is engrossed in an attention-demanding task to the extent that they fail to notice what may often be considered more than obvious (Pizzighello and Bressan 2008).

The transcripts show that some instructions are 'viewed' or read by the student, but they are very quickly forgotten (selective amnesia), and that other instructions that include cues to support informed use of the simulation, provided by the designers to guide the students, are missed (inattentional blindness) by the students.

Researcher: Did you notice that it had instructions, like the instructions had numbers on them?
H: No.
S: No.
Researcher: No. So, like on here there was a number one, a two,
H: I saw that bit, saw that bit down there.
Researcher: What bit?
H: That number four down there.
Researcher: What about number three then?
H: Where is number three?
(SMA HS)
A: I didn't really notice the number sequence no.
Researcher: So the order that you were doing it in was…
A: Was largely by the spacing, by where they were positioned.
(DHS 1)

The simulations were allocated randomly, and five pairs used a simulation illustrating a molecular level depiction for a reaction between an acid (HCl) and an alkali (NaOH). In the simulation, coloured spheres represent the ions/molecules in sodium hydroxide solution and hydrochloric acid. The following excerpt transcript is taken from a retrospective conversation between the researcher and two students as their digital record was replayed to them. It is representative of comments made by all five pairs/triad who used this simulation.

Researcher: Ok. Oh ok. So what do you think was happening?
Student 1: They were joining together. Or something.
Student 2: Becoming neutral.
Student 1: Neutrons.
Researcher: What was becoming neutral?
Student 1: The protons.

Student 2: And the minus ones.
Student 1: Electrons.
(SMA SJ)

As the transcript shows, these two students forgot that this simulation depicted an acid–base reaction. Instead, they are of the opinion that it represented atomic structure. Their attention was captured by the positive and negative symbols that remained on screen for the duration of the simulation, which they associated with simple protons and electrons rather than representing the charge on the ions. It could be argued that the students in using the phrase ‘becoming neutral’ were implying that they understood this to be an acid–base neutralization reaction. However, their follow-up comments indicate this is not the case; instead, they used the phrase neutral to refer to protons or electrons forming neutral subatomic particles, a completely different concept to that intended by the simulation. The text at the start of the sequence specifically stated that this simulation represented an acid base neutralization reaction. So, while the students confirmed they had read the information drawing attention to the fact that this was a neutralization reaction, they promptly forgot it as is evidenced when they described their interpretation of the reaction.

14.5 Study D: Tracking Student Engagement with Online Simulations

In order to explore the aspects identified in study C further, two of the simulations (titration and metals) were modified to take into account two of the three aspects: (1) distraction (redundant segments) and vividness (items that stand out) and (2) logic and instructions. The third aspect, prior knowledge, I felt was beyond my control in this particular study, though I felt I could collect information about their prior chemistry and ICT experience.

Study D was a collaboration with Eugene Gvodzenko, a mathematics educator. For study D, instead of generating a front of screen record of the screen activity, I wanted to develop a behind-the-scenes online tracking system for three versions of the same simulation. We asked Professor Thomas Greenbowe for access to the codes for the two simulations, and I asked Eugene to modify the codes to create three versions of the simulation and to allow us to track activity as the user used the simulation. The system Eugene created allowed us to randomly allocate one version of the two simulations and to record student activity as the allocated simulation was used. For study D, we opted for a behind-the-scenes recording of activity for three reasons. First, we believed that a behind-the-scenes track may be less intrusively gained and may generate more reliable data. Second, in many nations, collecting images of school children is being discouraged. By logging activity through behind-the-scenes tracks instead of filming the screen helped us address this issue. Third, we could

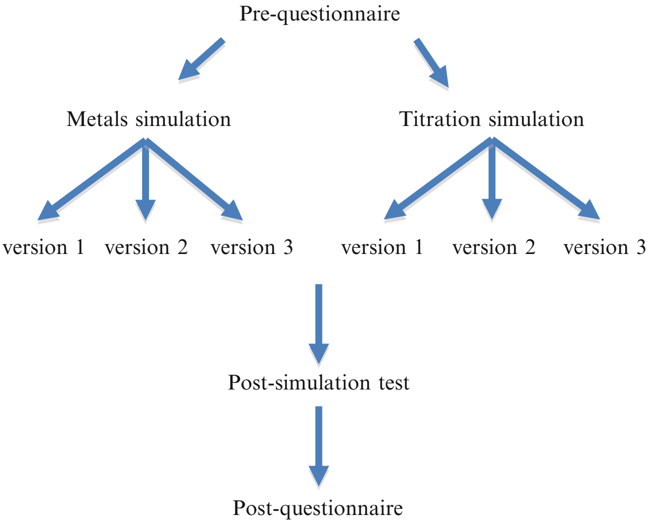


Fig. 14.1 The schematic that follows shows the basic pathway options

make a private Internet URL available to a cohort who may choose not to use the simulation within a classroom, and this would make filming them impractical. The simulations were the creation of Professor Greenbowe, and he, very kindly, agreed to provide the code that enabled Eugene to modify the presentation of the titration simulations. Two simulations, a metal reactivity (metals immersed in a metal compound solution and metals immersed in an acid) and an acid–base titration, were used in this study. Three versions of each of the two simulations were created (Fig. 14.1).

So, for example, a user would have to complete the pre-questionnaire before being randomly allocated to either a titration or metal simulation. They would then complete a pre-simulation questionnaire (specific to the chemistry topic for that simulation). They would then be randomly allocated to a version of the simulation. The computer would keep a track of the time they spent on each stage and go on to track the time they spent on particular elements of the simulation while they were using the simulation. When they opted out, they would be asked to complete a post-simulation test before exiting the programme.

In this chapter, we present findings for the acid–base titration simulation. There were three versions: the original version, version 2 which had a pre-text to encourage students to pay attention to particular aspects and version 3 which simply altered the position of elements on the screen. The following additional instructions appeared on the web page before version 2 of the titration simulation has been loaded:

> When you click on the button below you will see a simulation that represents a titration. To make the simulation work you must follow the numbered instructions in sequence. So start with instruction 1, then 2, then 3, etc. Some instructions have tabs. You must place the mouse on the tab and drag it open.

In version 3 of the titration simulation, the instruction for control −3 ‘Select the Acid and Base’ was converted from a ‘pull-out tab’ menu to a fixed position one, open menu. It also contained the instructions in a reading pattern that had a horizontal sequence of left to right.

Our convenience sample of volunteers was drawn from four schools and one tertiary institution in Scotland. We did not collect any data to identify the volunteers on a personal level, but they were automatically anonymously given an individual code, and the different institutions were recognized by the logging system. In this chapter, we only provide findings from those who submitted a questionnaire and went on to interact with a simulation. The volunteers provided their age, gender, science subject (science, chemistry, physics, biology) and class/tertiary level and indicated their previous ICT experience. They completed five multiple-choice chemistry questions before and after the simulation use.

There were 19 volunteers aged from 13 to 15 years (second year of secondary school) and 15 participants aged 16 and over, who were randomly allocated to a titration simulation. There were roughly equal numbers of male and female volunteers (17 females and 16 males) using this simulation. Two volunteers did not supply details about their age or gender.

The actual number randomly allocated to version 1 was very small, so in this chapter, we concentrate on the differences observed in the tracks for volunteers using version 2 and version 3. What we found was that there were notable differences in activity between these two versions.

Our findings show that five first year science undergraduates used version 2, and only one of them reached step 4 in the simulation version 2. In contrast, version 3 resulted in 12 of the 16 volunteers using the designer sequence in version 3. Four users chose the button 3, but their approach did not follow the sequence when using version 3. Therefore, all participants using version 3 found the instruction 3, regardless of age. Unfortunately, in contrast, ten of the version 2 volunteers had tracks with chaotic patterns. Furthermore, 10 of the 14 volunteers who were randomly allocated to version 2 had tracks that showed that they missed the instruction 3 – the tab pull-out menu. (This supports study C findings which also suggested that students missed the instruction 3.) Instruction 3 was fundamental to ensuring progress. In fact, without it the simulation simply could not proceed.

In contrast, all but 3 of the 16 volunteers had track data that showed that they followed the designer-intended sequence when they used version 3 of the simulation. This would suggest that having something as simple as a fixed screen menu makes a difference to progress through a simulation. Furthermore, the tracks for all volunteers who had been randomly allocated to version 3 of the titration show that they found (and used) the instruction 3. In contrast, several volunteers who were allocated to version 2 failed to find the instruction 3 and some of those who did took over 2–3 min to find the instruction 3, despite the fact that version 2 gave advance organizers and specific notice indicating the sequence to follow and the tab menu. Further details for this project can be found in Rodrigues (2011).

14.6 Discussion

All four studies (A, B, C and D) highlight the need to consider how the simulation product appears to students. Obviously, making it a pleasurable and enjoyable experience would more than likely make it more engaging. And the level, type, quality and quantity of accessible feedback will influence the scope of the product in supporting interaction. However, in designing simulations, the level, type, quality and quantity of accessible feedback needs careful consideration. As the findings for students involved in study B showed, many students cited 'video and text' as the most helpful presentation type to understand the science concepts. Given the ordinariness of the video footage, it was notable that these 11–13-year-old students preferred viewing video clips rather than animations. This may have been due to what some students reported as the difficulty they faced in attempting to read the screen information and observe the screen action at the same time. The ordinariness of the video footage may have provided an opportunity for them to simply focus on reading the text. Indeed, students' aversion to 'risk taking' was also seen in the fact that students navigated a safe and repeatable route when they used the periodic table in study A. The students in study A and study B did not appear to have a favourable disposition towards inquiry. In our future research, we hope to explore whether students in formal learning environments balance or consider engaging and motivating digital software against the need to access information to support their learning. Students' behaviour in the periodic table (study A) suggests the students opted for engagement (often more interested in their score on the quiz rather than what they learnt about the periodic table by doing the quiz). In contrast, students' behaviour in the physical change (study B) suggests the students opted for information gathering, preferring to view water boiling or ice melting rather than watching animated atoms and molecules when reading text about the process.

The appearance of material also has a vital part to play in terms of engagement and progress. All four studies showed that students were keen to make progress through the simulation. However, studies C and D showed that vivid items caught the eye and tended to result in students failing to see the designer-intended instruction sequence. In addition, studies C and D in particular highlighted the impact of inattentional blindness.

The most famous example of inattentional blindness is the Chabris and Simons (2010) gorilla and basketball team study (the study was replicated and is easily accessed via Youtube video clips). In the Chabris and Simons (2010) original study, observers are asked to view a digital record and count the number of ball passes made by one of the teams. During the course of the digital record, a gorilla-suit-wearing-participant saunters through the basketball teams. The Chabris and Simons (2010) study showed that a significant number of people viewing the digital record fail to see the gorilla. While our projects were not so dramatic, our findings are similar. In studies C and D, our findings showed that users engaging with these attention-demanding simulation tasks failed to notice what may have been considered obvious by the software designers.

In addition, our findings would suggest some simulation users demonstrate selective amnesia. In study D, the volunteers who were randomly allocated to the version 2 of the titration software received hints about following the sequence and accessing the tab menu. Yet, many simply forgot to pay heed to this instruction. In study C, students clearly stated that they read specific information that appeared on the screen regarding what the simulation was depicting (neutralization reaction). And yet when they were asked to describe what the simulation was depicting, many failed to relate the movement of the spheres to neutralization and instead identified the simulation as an atomic level depiction (protons, neutrons and electrons). This may have been compounded by the fact that the simulation depicted the spheres with charges, which remained on screen for the duration of the simulation. This finding also suggests that vividness is important. The users noticed the charges just as they, using the titration simulation, noticed the icons or symbols that appeared in red as indicated in study C.

Much of the e-learning rhetoric in chemistry education has for many years alluded to notions of learner control, proactive learning or increased student engagement and motivation. There have been discussions on how e-learning tools have the potential to promote learning. Further, we have seen literature signalling the role and influence of e-learning design functions, such as the intuitive signals provided by icons or the scope for user initiative and self-pace through user-friendly navigation. Perhaps what we also now need to consider in more detail is the fundamental design of interactive, simulation-based, learning systems that are intended for use in chemistry classrooms. There is literature reporting on issues designers need to consider. For example, Barker (2008) suggests that at present there are ten factors that designers are encouraged to consider. These factors include (1) learning theory mix, (2) instructional position mix, (3) machine character mix, (4) environmental factors, (5) mode of use, (6) locus of control, (7) extent of intervention, (8) aesthetic features, (9) content and (10) the role of technology. Barker (2008) acknowledges that his list of factors is fairly general and applies to the development of interactive learning resources in a fairly generic way.

The findings from research presented in this chapter are an attempt to provide more detail with regard to the factors that need to be considered when developing interactive resources for chemistry education.

14.7 Conclusion

While I acknowledge that not all learning can be engineered, and some learning is often serendipitous, I think it is important that we ensure that the learning environments that are deployed in order to help engineer learning (in our case, learning chemistry) do not inadvertently defeat the object of the exercise. The findings from the first-phase project suggested that e-assessment involving the use of multimedia or iconic or symbolic representation in chemistry education will have to take great care if it is to ensure that what it is assessing is the students' chemistry capability and not their (lack of) information processing skills that rely on shared symbol identification or on the ability to follow the designers' logic of instructions.

Our research findings suggest that designers developing materials for use in chemistry education should ensure a balance that addresses the following four aspects:

1. Use words/symbols and images, but when they do so, they should ensure that they do not support inattentional blindness or build in a subconscious value system to the words/symbols by keeping some words/symbols in for longer durations or permanently. The research findings showed, for example, that text informing students about the nature of the simulation (neutralization) was soon forgotten or missed when the students engaged with a simulation that kept charge symbols in the simulation for the duration of the simulation, which led them to believe the simulation represented atomic structure.
2. Ensure the timing or location of images and narrative is close so as to minimize selective amnesia. The research findings showed that some users who were given instructions that directed them to follow particular sequences before they commenced using the simulation failed to take heed of the instruction and the majority was therefore unable to complete a titration simulation.
3. Present oral rather than on-screen text when depicting unfamiliar symbolic content when designing simulations. Research findings showed that simulations which students perceived to be of interest were not pursued when they were unable to digest the written information that accompanied screen action. Instead, they reverted to viewing screens with familiar macroscopic events that allowed them to read the text confidently that they would not have missed any screen action.
4. Consider the aesthetics but also consider the value system afforded to elements within the design that draw attention due to their size, colour or location. Research findings showed that vivid items (prominent red buttons) and location (tab menus) affected progress when using an acid and base titration simulation.

Our findings and the literature in general suggest that cognitive load may be a problem in classrooms, but in recreational computer use (games mainly), cognitive load is not an issue. This conflict in view may be due to students' beliefs, their assessment of the purpose of the task and the resulting mindful or mindless engagement. Their perception of the type of goal set for them and their perception of the purpose of the task in the e-science classroom may lead them to focus on performance goals (as was seen in our studies A and B). In some of the literature relating to the area of prior knowledge, there is a suggestion that students have to use higher-order information processing skills in science classrooms where ICT is used (as was seen in our studies C and D). However, the fact that reports (see, e.g. Cuban 2001) continue to signal that practice involving the use of various technologies has not changed significantly, the development of digital literacy in science education environments is most likely incidental. Digital literacy needs to be taught more explicitly in science classrooms if the available technology is to do more than simply provide increased amounts of better-presented data in chemistry classrooms. The student must make connections between coming to know and understand (cognition), make decisions about how they feel about the task (affect) and decide how to translate cognition and affect into intentional behaviour (conation). In a science lesson, these elements may not be triggered or used automatically by simply immersing the student in an e-learning environment. So, while multimedia technology has the potential to support learning in chemistry classrooms, it is only likely to be realized if classroom practice, expectation and behaviour change.

References

Azevedo, R. (2004). Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist, 40*(4), 199–209.

Barker, P. (2008). Re-evaluating a model of learning design. *Innovations in Education and Teaching International, 45*(2), 127–141.

Barton, R. (2002). *Teaching secondary science with ICT*. Cambridge: Open University Press.

Barton, R. (2004). *Teaching secondary science with ICT*. Cambridge: Open University Press.

Chabris, C., & Simons, D. (2010). *The Invisible Gorilla: And other ways our intuitions deceive us*. New York: Crown Publishers.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition & Instruction, 8*(4), 293–240.

Chandler, P., & Sweller, J. (1992). The split-attention effect as a factor in the design of instruction. *British Journal of Educational Psychology, 62*(2), 233–246.

Clarke, R., & Mayer, R. (2003). *E-Learning and the science of instruction*. Proven guidelines for consumers and designers of multimedia learning, California: Pfeiffer.

Cuban, L. (2001). *Oversold and underused: Computers in schools 1980–2000*. Cambridge, MA: Harvard University Press.

Deaney, R., Ruthven, K., & Hennessy, S. (2003). Pupil perspectives on the contribution of information and communication technology to teaching and learning in the secondary school. *Research Papers in Education, 18*(2), 141–165.

Eilks, I., Witteck, T., & Pietzner, V. (2010). Using multimedia learning aids from the Internet for teaching chemistry – Not as easy as it seems? In S. Rodrigues (Ed.), *Multiple literacy and science education: ICTS in formal and informal learning environments* (pp. 49–69). Hershey: IGI Global.

Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction, 15*, 313–331.

Hill, D. (1988). Misleading illustrations. *Research in Science Education, 18*(1), 290–297.

Hutchby, I., & Wooffitt, R. (1998). *Conversation analysis: Principles, practices and applications*. Cambridge: Polity Press.

Kirriemuir, J., & McFarlane, A. (2004). *Report 8: Literature review in games learning*. A report for NESTA Futurelab. http://www.nestafuturelab.org/research/reviews/08_01.htm

Koeber, C. (2005). Introducing multimedia presentations and a course website to an introductory sociology course: How technology affects student perceptions of teaching effectiveness. *Teaching Sociology, 33*(3), 285–300.

Mayer, R. E., Sobko, K., & Mautone, P. D. (2003). Social cues in multimedia learning: Role of speaker's voice. *Journal of Educational Psychology, 95*, 419–425.

Moreno, R. (2006). Does the modality principle hold for different media? A test of the methods-affects-learning hypothesis. *Journal of Computer Assisted Learning, 22*, 149–158.

Ng, W. (2010). Empowering students to be scientifically literate through digital literacy. In S. Rodrigues (Ed.), *Multiple literacy and science education: ICTS in formal and informal learning environments* (pp. 11–31). Hershey: IGI Global.

Paivio, A. (2006). *Mind and its evolution; a dual coding theoretical interpretation*. Mahwah: Lawrence Erlbaum Associates, Inc.

Pizzighello, S., & Bressan, P. (2008). Auditory attention causes visual inattentional blindness. *Perception, 37*(6), 859–866.

Ploetzner, R., Bodemer, D., & Neudert, S. (2008). Successful and less successful use of dynamic visualizations. In R. Lowe & W. Schnotz (Eds.), *Learning with animation – Research implications for design* (pp. 71–91). New York: Cambridge University Press.

Rodrigues, S. (2000). The interpretive zone between software designers and a science educator: grounding instructional multimedia design in learning theory. *Journal of Research on Computing in Education, 33*, 1–15.

Rodrigues, S. (2003). Conditioned pupil disposition, autonomy, and effective use of ICT in science classrooms. *Kappa Delta Phi: The Educational Forum, 67*(3), 266–275.

Rodrigues, S. (2007). Factors that influence pupil engagement with science simulations: The role of distraction, vividness, logic, instruction and prior knowledge. *Chemical Education Research and Practice, 8*, 1–12.

Rodrigues, S. (Ed.). (2010). *Multiple literacy and science education: ICTS in formal and informal learning environments*. Hershey: IGI Global.

Rodrigues, S. (2011). Using chemistry simulations: Attention capture, selective amnesia and inattentional blindness. *Chemistry Education Research and Practice, 12*(1), 40–46.

Rodrigues, S., Smith, A., & Ainley, M. (2001). Video clips and animation in chemistry CD-ROMS: Student interest and preference. *Australian Science Teachers Journal, 47*, 9–16.

Rogers, L., & Finlayson, H. (2003). Does ICT in science really work in the classroom? Part 1, the individual teacher experience. *School Science Review, 84*(309), 105–111.

Sanchez, E., & Garcia-Rodicio, H. (2008). The use of modality in the design of verbal aids in computer based learning environments. *Interacting with Computers, 20*, 545–561.

Schnotz, W., & Bannert, M. (2003). Construction and interference in learning from multiple representations. *Learning and Instruction, 13*(2), 117–123.

Schwartz, N., Andersen, C., Hong, N., Howard, B., & McGee, S. (2004). The influence of metacognitive skills on learners' memory of information in a hypermedia environment. *Journal of Educational Computing Research, 31*(1), 77–93.

Segall, A. (2004). Revisiting pedagogical content knowledge: The pedagogy of content/the content of pedagogy. *Teaching and Teacher Education, 20*(5), 489–504.

Testa, I., Monroy, G., & Sassi, E. (2002). Students' reading images in kinematics: The case of real-time graphs. *International Journal of Science Education, 24*, 235–256.

Trindade, J., Fiolhais, C., & Almeida, L. (2002). Science learning in virtual environments: A descriptive study. *British Journal of Educational Technology, 33*(4), 471–488.

Wardle, J. (2004). Handling and interpreting data in school science. In R. Barton (Ed.), *Teaching secondary science with ICT* (pp. 107–126). Cambridge: Open University Press.

Chapter 15
Integrating Digital Technologies into the Contemporary Science Classroom

Karen Murcia

15.1 Introduction

Educational technologies such as the interactive whiteboard (IWB) have the potential to expand the way students experience learning and teaching by increasing access to multimedia resources and multimodal representations of concepts. It is argued that in the digital age, Information Communication Technology (ICT) is central to advancing science education and improving student outcomes (Hackling and Prain 2005; Lee 2010). This view is evident in the Australian School Science Education National Action Plan, which stated 'students learn science by seeking understanding from multiple sources of information, ranging from hands-on investigation to internet searching' (Goodrum and Rennie 2007, p. 14). Teachers' pedagogy must evolve to meet the demands of changing classroom environments and learning needs of contemporary students. The interactive whiteboard (IWB) is an example of an educational technology that can be used to connect with students' digitally aware everyday experiences, particularly in the way information is accessed and manipulated. When used effectively, IWB technology can support or extend learning and teaching opportunities in contemporary classrooms (Higgins et al. 2007; Murcia 2008; Betcher and Lee 2009). The IWB can be used by teachers as a converging tool, bringing a range of Information and Communication Technologies (ICTs) and multimedia learning activities to the front of the classroom. Learning and teaching in the IWB classroom occurs on the social plane of the classroom and encourages an environment where students co-construct understanding by using ICTs for extending how they access, develop and demonstrate knowledge.

Interactive whiteboard (IWB) technology has been identified in Australia and internationally as a tool that can bring together a range of ICTs in daily classroom practice (Betcher and Lee 2009) and potentially increase opportunities for students

---

K. Murcia (✉)
Edith Cowan University, Faculty of Education and Arts, Perth, WA, Australia
e-mail: k.murcia@ecu.edu.au

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_15,

to experience multimodal representations of science (Littleton 2010). The technology enables students and teachers to interact with all the functions of a desktop computer through the IWB's large touch-sensitive surface fixed at the front of the classroom. When used appropriately, features of an IWB and the associated software have the potential to actively engage students in learning by enhancing the interactivity between the teacher, the science learning resource and students (Murcia 2008; Betcher and Lee 2009). Software tools and simple design techniques promote active learning with manipulations such as drag and drop, hide and reveal, highlighting and annotating with digital ink matching equivalent terms and movement for sorting and classifying (Higgins et al. 2007). The enhanced interactivity and the 'drag ability' of text and objects on the board's surface add another dimension to traditional learning and teaching (Murcia and McKenzie 2008; Betcher and Lee 2009). However, we must be mindful of the fact that the technology is only a tool to support or extend learning and teaching strategies. It is critical that the technology does not drive the science curriculum but rather it is used to enhance learning and teaching at appropriate times. Educators need to go beyond simply understanding technological changes and to further understand the impact of the change on learning and teaching. Greater understanding of the impact of digital tools on learning and teaching is required as they have the potential to change the way knowledge is represented and re-represented. It is important to understand the specific ways in which technologies such as the IWB work as a mediating or convergence tool for a wide range of multimodal representational types.

In this chapter, principles of pedagogical interactivity and multimodal representation are used as a conceptual framework for exploring and discussing the use of IWB technology in primary science classrooms. This interactive multimodal lens was placed over a series of action research case studies conducted over 2 years with eight Western Australian primary school teachers. Snapshots of three of these teachers' classrooms are provided as illustrative examples of the types of representation and emerging principles of interactive pedagogy observed across participants in the research hub. These snapshots include pages from the teachers' interactive notebooks and descriptive narratives, which highlight the ways that students' experience and use representations of science concepts in their IWB classroom.

15.2 Pedagogical Interactivity

The uptake of IWB technology internationally and nationally is in part due to its compatibility with existing teaching practices. Unfortunately, the IWB is not always used productively or to its full potential. Like many technology-led initiatives in education, the installation of an IWB is not always accompanied by an adequate understanding of the technology's impact on pedagogy (Warwick and Kershner 2006). The tool has been observed complementing traditional teacher-led, whole-class learning where the IWB is simply used as a surface for writing notes or projecting images. However, the IWB has also been found to offer possibilities for expanding and even reinvigorating teachers' pedagogy (Higgins et al. 2007). Teachers using effective interactive pedagogies do much more as they become 'critical agents in mediating the technology to provide a more dynamic, interactive and appropriate learning experience' (Rudd 2007, p. 6).

There is a changing pedagogical role for the teacher in ICT rich interactive whiteboard classrooms. A classroom enhanced with digital educational technologies requires interactive pedagogy. The technology can be used actively to facilitate interaction with and between students and immediate constructive feedback to the students (Beauchamp and Kennewell 2008). Pedagogical interactivity is the mediation of interaction between the teacher, students and the technology, which is a complex process that extends beyond basic manipulations of the technology (Tanner et al. 2005). Pedagogical interactivity is the integration and intersection of activity that occurs at the board, at students' desks and in the minds of the students. This includes technical interactivity with a focus on using the tools of the board, physical interactivity focussing on students' manipulation of objects at the board's surface and conceptual interactivity, which focuses on using the board to explore and construct understanding of concepts (Deaney et al. 2009). Jewitt (2006, p. 76) stated, 'It is essential to understand what resources new technologies make available and how these mediate the complex relationship between the learner and what is to be learnt'. This suggests that fully exploiting the potential of interactive whiteboards requires educators to go beyond simply understanding the technology itself and achieving technical competency to understanding the impact of the technology on pedagogy and students' science learning. Tanner et al. (2005, p. 723) represented the nature of whole-class pedagogical interactivity on a five-point continuum, ranging from a lecture approach with high teacher control to a collective approach with a high degree of pupil control. Question types and the nature of whole-class discourse were indicators of pedagogical interactivity:

1. Lecture: No interactivity or only internal interactivity
2. Low-level/funnelling questioning: Rigid scaffolding and surface interactivity
3. Probing questioning: Looser scaffolding and deeper interactivity
4. Focusing or uptake questioning: Dynamic scaffolding and deep interactivity
5. Collective reflection: Reflective scaffolding and full interaction

Opportunities for learning in an interactive whiteboard classroom are enhanced when students are given the opportunity to make their ideas public, participate in rich dialogic discourse in which concepts are shared and vocabulary is developed and practised (Warwick et al. 2006; Hackling et al. 2010). Furthermore, Murcia (2008) found that the IWB created a fluid space where interactive communication allowed the teacher and students to 'explore science ideas together, pose questions and reconcile scientific and informal ideas' (p. 20). Integrated with reported interactive activities were higher-order questions and student-led discussions: 'Questioning was the means for focusing students' attention, provoking action and for making connections' (Murcia 2008, p. 20). Teachers have been observed using the interactive affordances of the IWB technology to support dialogic interactivity by using questioning around images and actions to elicit and clarify student's ideas and build joint understanding through exploratory dialogue (Mercer et al. 2010). Higgins et al. (2007, p. 216) in their review of the literature on interactive whiteboards further identified research evidence that ‘interactivity is most effectively sustained through effective questioning as well as a wider range of activity’. Strategies for managing effective questioning and discussion are a key dimension of productive interactive pedagogy.

Students and teachers can use the tools of the IWB and integrated ICTs to socially construct shared meaning through whole-class collaboration. In a social constructivist science classroom, where it is assumed knowledge and understanding are actively constructed through social interactions and not passively received from the teacher or environment, teachers match the use of technology to learning objective goals and outcomes. The sequence and nature of activity in a constructivist programme must be matched appropriately to the stage of scientific enquiry (Hackling et al. 2010). Teachers exercise professional judgement and identify when and how the technology can support students learning and achievement of curriculum outcomes. They go beyond technical competence to understanding and using pedagogical interactivity to facilitate students’ enquiry and development of scientific understandings.

15.3 Multimodal Representations in the IWB Science Classroom

Interactive practices in the IWB classroom include accessing a range of multimodal representations and creating opportunities for students to experience knowledge and demonstrate what they know in an increase range of modes (Murcia 2010; Twiner et al. 2010). In this context, the term mode is referring to the form of the content such as discourse, image or writing (Twiner et al. 2010). Jewitt (2006, p. 2) suggests the multimodal affordances of digital education technologies such as the IWB are changing the nature of the classroom and states, ‘these different or new potentials require a rethinking of what it means to learn’. Learning is a gradual process of constructing knowledge, skills and understanding and is arguably the result of a transformation process and internalisation of cultural signs and symbols (Jewitt 2006). This view places modes of representation and communication at the centre of learning.

Specifically, science as a discipline is multimodal, that is, it involves the negotiation and production of meanings in different modes of representation ranging from descriptive text, experimental, to figures and images. Lemke (1998, p. 1) argued that multimodal representations of concepts were central to learning science. He stated, ‘We need to see scientific learning as the acquisition of cultural tools and practices, as learning to participate in very specific and often specialised forms of human activity’. To understand the values, language and practices of science, children need to experience multimodal representations and explorations in the classroom. Prain and Waldrip (2006) describe these modes as descriptive (verbal, graphic, tabular), experimental, mathematical, figurative (pictorial, analogous and metaphoric) and kinaesthetic or embodied gestural understandings or representations of the same concept or process. New understandings are generated through multimodal representations of ideas, affective responses and evidence-based judgements (Tytler 2007; Warwick and Kershner 2006). When learning takes place, students have experienced cognitive growth and conceptual change or development. They talk about and describe concepts in new ways with different meanings. From this perspective, greater emphasis is required on metacognitive practices or more simply how students construct meaning from multimodal representations. In order to understand the values, language and practices of science, students need to experience multimodal representations and opportunities to re-represent concepts in the classroom. More emphasis is placed on the role of the teacher as someone who models and scaffolds for students how to talk and write about science, how to construct diagrams and calculate and how to investigate and inquire in order to develop and make sense of new knowledge (Tytler et al. 2006; Murcia 2010).

Multimodal fluency in representing and re-representing would be an indicator of conceptual understanding in science and should be central in teaching and learning. For example, Hand et al. (2009, p. 226) propose that all classroom learning should be focused around the understanding that ‘meaning making is multimodal’ and as such students need to ‘develop multi-literacies as a function of learning’. A social constructivist approach to learning would support the assertion that students’ conceptual understanding develops as they generate and transform representations experienced in one mode to another. Research has suggested that multimodal representations not only motivate learners but lead them to a deeper understanding of the subject being taught (Ainsworth 1999).

15.4 An IWB Research Hub

Placing a framework of pedagogical interactivity and multimodality over real classroom environments has contributed insights to the important questions, reported by Lee (2010) as being raised by education stakeholders in relation to how the introduction of IWB technology is influencing educational practices. Researchers from Edith Cowan University in Western Australia worked in partnership with classroom teachers to develop evidence-based understandings of interactive whiteboard technology’s impact on whole-class learning and teaching. For 2 years, the university hosted an interactive whiteboard research ‘hub’ or network of primary and secondary school science teachers and administrators who worked together to understand how teachers use an IWB in the teaching and learning of science and how children use the IWB to show what they know. The participating teachers ranged in their experience with integrating IWB technology into classroom practice from first-time users to 3 years. All research activities and data collection occurred in conjunction with their normal classroom science programmes.

15.4.1 Action Research and Teachers' Professional Learning

Action research principles provided a dual focus within all hub communications, meetings and workshops, on teachers' professional learning and deep understanding of the IWB classroom environment. Weinstein (1995) described action research as a way of learning from our actions and from what happens around us by taking the time to question and reflect on this in order to gain insights and consider how to act in the future. The project structure aimed to facilitate practical action, based on the learning needs and interests of the participating teachers, while supporting the teachers' professional learning about IWB technology and pedagogical interactivity in science. The research was intended to be a participatory process, alternating between planning, acting, describing and critically reflecting (Murcia 2005). The teachers were encouraged to contribute to the research by sharing and reflecting on their practice in their science classroom. This occurred when researchers visited the teachers at their school and at hub meetings held at intervals throughout the school year. These meetings were critical to maintaining the momentum of the research, as well as teachers' attention to multimodal representational strategies, pedagogical interactivity and their development of IWB technical skills. Data gathered for the case studies included semi-structured interviews, video-captured lessons, classroom observation field notes, student work samples and interactive notebooks produced by the teachers.

15.4.2 Video Capture and Analysis

The technology-based and interactive nature of the IWB learning environment required video recording of classroom action in order to capture and understand the dynamic modes of learning and teaching in the science lessons. A holistic view of the classroom and teaching and learning experiences was required as the research, focused only on discourse and or written text, would have stripped away the interactive multimodal features of the IWB context (Jewitt 2006). Video recordings of science lessons were made using a single camera with a wide-angle lens placed at the back of the classroom out of the students' line of sight, to minimise its influence on classroom activity. Field notes from lesson observations were produced concurrently with video capturing, and teachers' IWB notebooks were collected in order to assist in the analysis of IWB practice.

15.5 A View of IWB Science Classrooms

Classroom observations and the video data showed a range in the level of interactive pedagogy demonstrated by teachers during a full lesson and a series of lessons. All teachers used the IWB for different purposes during the science enquiry process.

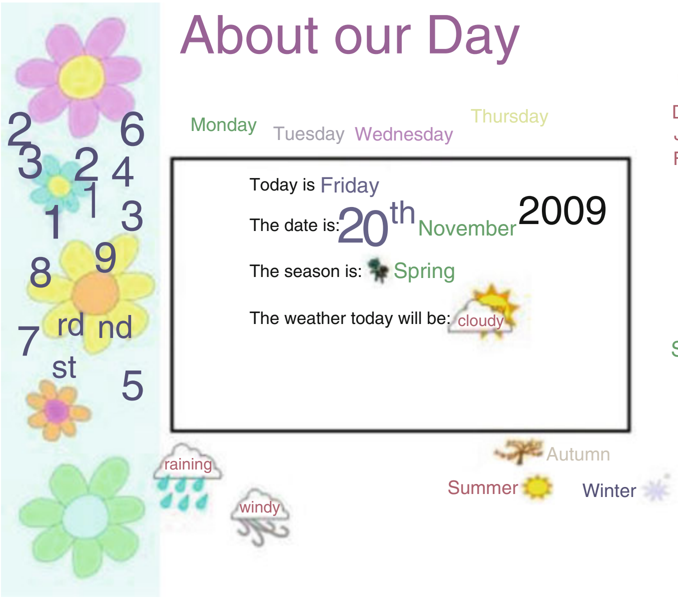
At times, students were passive in the IWB learning experience as they watched videos or listened to teacher talk. At other times, there was much greater control of the interaction by students, with students asking questions, engaging in whole-class exploratory talk and representing their understanding through original representations such as a short multimedia recordings or diagrams created and annotated on the IWB.

The following examples of classroom action, orchestrated by teachers using an IWB, were selected from the data set as they illustrated deeper interactivity. Each is, however, only a static representation of sections of the learning and teaching occurring in each classroom. The video data captured the full dynamic nature of the interactive pedagogy in each lesson that incorporated, for example, the movement of images, annotation of text and substantive discussions of science ideas. Each image displayed below is a single ‘page’ from a case study teachers’ interactive science ‘notebook’. Each set of pages represents a snapshot of the total activity occurring in the learning sequence. The teacher narrative included with each image draws from the multiple sources of qualitative research data and synthesises emerging themes from the case study. The narrative captures the teachers’ ideas and actions surrounding their development and classroom use of the IWB-supported representations of science.

15.5.1 Teacher Wendy: Weather in My World

Wendy came to the IWB research hub as a year 1/2 split class (ages 6–7) teacher in a metropolitan area government primary school. At the start of the project, Wendy had been using the IWB with her students for approximately 3 months. She had already found a range of benefits in using the IWB to support teaching and learning. In particular, she commented on children’s motivation to use the technology. For example, ‘The children love to come up and put answers on the board. They love to draw pictures; they love to interact, moving things across the board’. Wendy’s science programme was focussed on Investigating and Earth and Beyond outcomes from the Western Australian Curriculum. She used the Primary Connections resource *Weather in My World* (Australian Academy of Science 2007) to structure the 8-week science programme from which the following snapshots of IWB action were taken.

Wendy’s learning activities and narratives (Figs. 15.1, 15.2 and 15.3) together illustrate the range of multimodal representations brought into the classroom through the use of the interactive whiteboard technology. Wendy’s narratives highlight her use of IWB tools and interactive pedagogies to promote and support students’ engagement with a range of representations of the concept of weather and temperature. She used visual and experimental representations of the concepts to support her questioning and facilitation of classroom discourse. She explained, ‘I use pictures and questioning about what’s observed, which often stimulates a lot of talk’. Her mediation of the IWB technology with students was supported by questioning aimed at promoting whole-class exploratory discourse, which was an integral aspect



Today is Friday

The date is: 20th November 2009

The season is: Spring

The weather today will be: cloudy

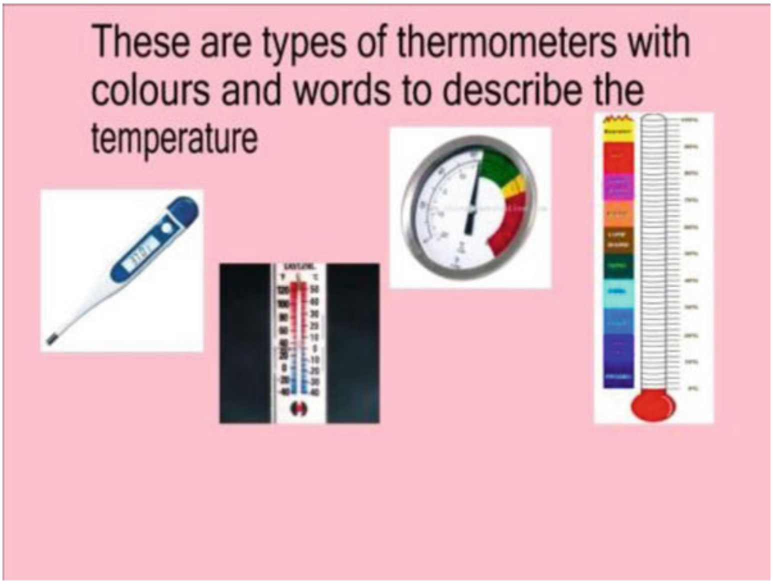
Fig. 15.1 A page from the class's weather book

Wendy's Narrative One: Weather Watching and Recording.

Our science topic for this term is weather, so I start each day by asking the children to look out the window, make observations and talk to me about the day's conditions. We recorded the day's forecast on the IWB into our weather book (interactive notebook). The children have learned that we show weather with symbols. They take turns to drag the weather symbol into the day's record.

of the interactive pedagogy used at each stage of the Weather in My World lesson sequence. Her students were encouraged to ask questions and explore possible answers when exposed to multiple sources and representations of information available through the use of the IWB technology. Wendy scaffolded the students' re-representation of their verbal accounts of the day's weather to a symbolic representation, with a range of questions that encouraged children to talk about what they observed and how they could record their information.

While using the IWB, she was able to quickly access multimodal representations of temperature and in a range of multimedia formats, which generated opportunities for students to talk through their ideas and socially construct understanding. The colourful visual display was clearly interesting but being able to interact with the symbols and try out ideas by dragging images motivated the children and encouraged substantive science talk.



These are types of thermometers with colours and words to describe the temperature

Fig. 15.2 Representing temperature with words and colour

Wendy's Narrative Two: Multimodal Representations of Temperature.

I have been questioning the children about how colour is used to represent temperature in the home, and they related this to the red hot water tap and blue cold water tap. I then showed them some different types of thermometers on the IWB and how each used colour, numbers and words to show temperature.

15.5.2 Teacher Lucy: Spinning in Space

While involved with the IWB hub, Lucy was teaching a year 6/7 split class (ages 11–12) in a metropolitan area government primary school. Lucy was introduced to IWB technology at the start of the research project. She had previously seen the technology demonstrated and as such was keen to have an IWB installed in her classroom. She stated, 'It is the way teaching is going. Technology is a big part of the students' lives and we as teachers need to begin incorporating more technology into our lessons'. Lucy's science programme was focussed on Investigating and Earth and Beyond outcomes from the Western Australian Curriculum. She used the Primary Connections resource *Spinning in Space* (Australian Academy of Science 2007) to structure the 8-week science programme from which the following snapshots of IWB action were taken (Fig. 15.4).

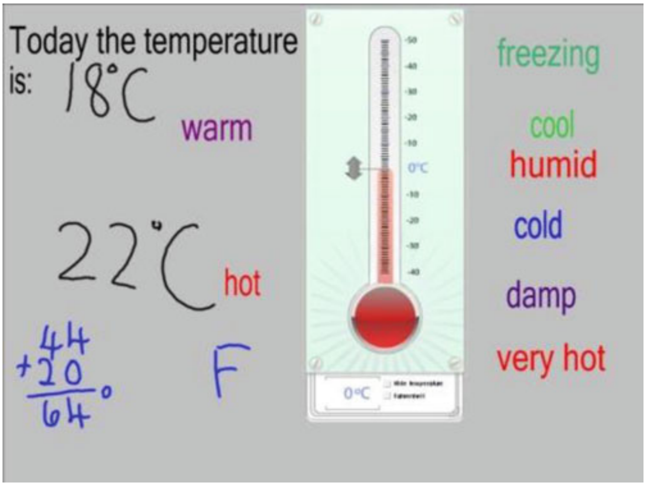
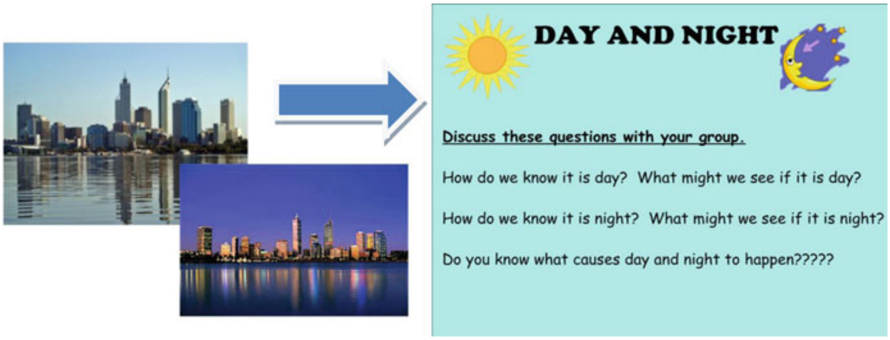


Fig. 15.3 Re-representing temperature numerically

Wendy's Narrative Three: Facilitating the Translation Process Between Modes of Representation.

I also asked then questions about the nightly weather report on television, which got them thinking about why we want a prediction of the next day's weather. They have become really interested in the daily temperature and like to find out if it matched the prediction from the weather report. We discuss the temperature each morning and then put a thermometer outside. We bring the thermometer back in at the end of the day, read the temperature, write it up on the IWB and then talk about how we feel at that temperature. This has meant that I could extend them by introducing the interactive thermometer, the idea of a scale and showing the days temperature as a number. A couple of the children noticed both the Fahrenheit and Celsius scale on the thermometer. This lead to some numeracy in science as they tried converting the day's temperature from Celsius to Fahrenheit.

Pictures, diagrams and photos were imported or captured by Lucy to produce visually appealing notebooks. These were displayed and interacted with as Lucy and her students edited, moved objects and annotated information at the board. Lucy used visually appealing displays to engage her students and reported her finding that the IWB increased her classroom access to resources. She stated, 'Resources that were unavailable to us before are now easily brought in through the IWB. Instead of me trying to photocopy pictures or find pictures in books and things like that we can use the internet and bring pictures up'. Importantly, Lucy and the students had



DAY AND NIGHT

Discuss these questions with your group.

How do we know it is day? What might we see if it is day?

How do we know it is night? What might we see if it is night?

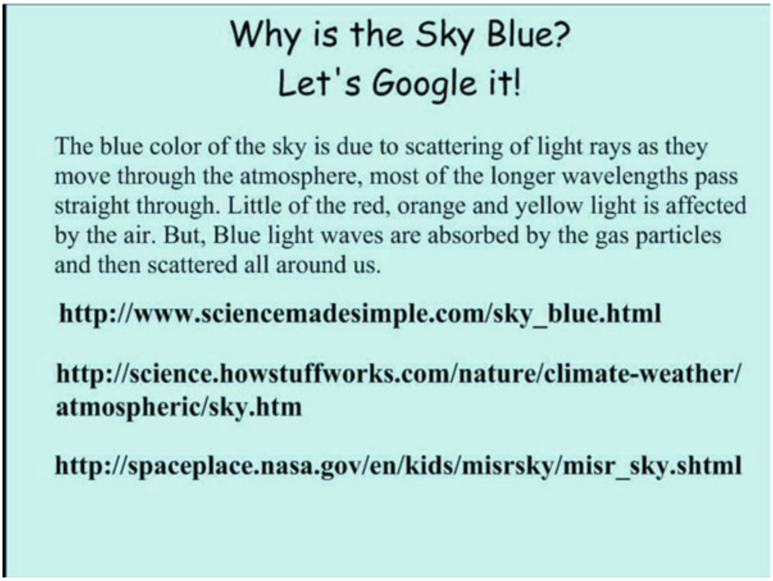
Do you know what causes day and night to happen?????

Fig. 15.4 Questions promoting group discussion of day and night photos

Lucy's Narrative One: Converging Images and Questions to Promote Exploratory Discussion.

I have used the IWB notebook to organise my lessons. It helped my teaching because I could do a whole programme or plan in a notebook. In the Spinning in Space notebook I made sure each slide followed on logically, which helped with connecting ideas, linking to the Internet, videos and basically building up the science story. I've got my questions there and the expectations for the students are there in black and white on the whiteboard. It also allowed me to bring resources from the Internet into the classroom. Instead of me trying to photocopy pictures or find pictures in books, I used the Internet and brought pictures up and displayed them on the IWB. I used two photos of the Perth city sky line, taken at different times of day for getting the students thinking and talking about the differences in day and night. I put a lot of the lesson's questions up on the interactive whiteboard so they're there for the students to use. I've learnt how to use the screen in the IWB software, so now I can uncover questions as needed. This is really good as it means I can make the students take time to think rather than rushing ahead.

moved beyond only using the IWB as a display tool as they were purposefully interacting with the images through annotation and discussion. Lucy also used a range of IWB tools for enhancing her questioning techniques and strategies. These included the use of the screen and spotlight functions, which she used to increase the wait time after a question and provide space for students to think. She explained, 'you might have the answers hiding under the screen but you just want the children to think about it before you bring it up. Students need a lot of prompting from time to time. So using the screen again or the hide-and-reveal or click-and-reveal activities just helps them. It gives them extra time and you see the students think, oh yeah, I've got another idea' (Fig. 15.5).



Why is the Sky Blue?
Let's Google it!

The blue color of the sky is due to scattering of light rays as they move through the atmosphere, most of the longer wavelengths pass straight through. Little of the red, orange and yellow light is affected by the air. But, Blue light waves are absorbed by the gas particles and then scattered all around us.

http://www.sciencemadesimple.com/sky_blue.html

http://science.howstuffworks.com/nature/climate-weather/atmospheric/sky.htm

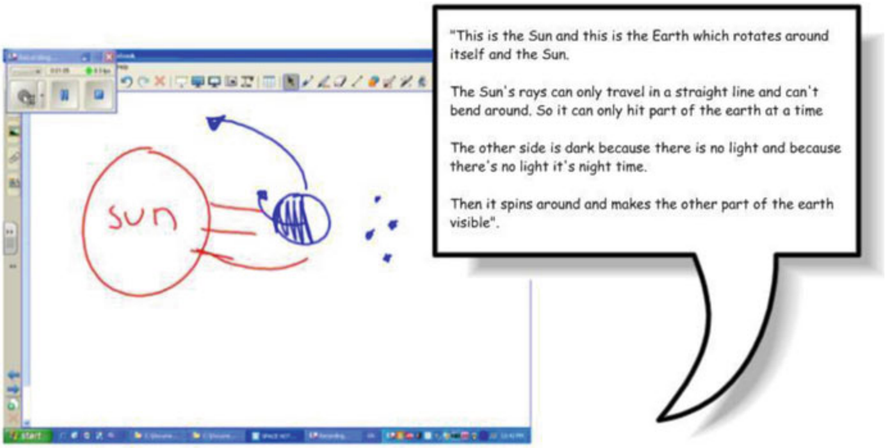
http://spaceplace.nasa.gov/en/kids/misrsky/misr_sky.shtml

Fig. 15.5 Linking to Internet sites and building information

Lucy's Narrative Two: Students' Questions and Finding Answers on the Internet.

We were having a class discussion about day and night and a student said, 'Well, why is the sky blue?' The students then started with ideas. One student said, 'Isn't it like a reflection or something but there's really nothing there' and somebody said, 'Doesn't it have something to do with colours and light'. I didn't know the answer so we decided to go and check. We went to the interactive whiteboard and we brought up the Internet, and together we found explanations, which we copied into the growing Spinning in Space notebook. It was good as questioning lead to questioning, which lead to learning which then lead to more questioning and lots of discussion.

A range of online learning resources were accessed via links embedded by Lucy into her interactive notebook. She selected websites that provided current information about science concepts or relevant contexts or examples. Lucy and her students were observed highlighting key words in the online text and underlining so as to focus thinking and whole-class talk. For example, Lucy explained 'I would bring up text on the board, highlight points with the (*digital ink*) pen and discuss with the students. Other times I would copy and paste text into the notebook and insert the link as a reference'. Lucy and her students were using the IWB



"This is the Sun and this is the Earth which rotates around itself and the Sun.

The Sun's rays can only travel in a straight line and can't bend around. So it can only hit part of the earth at a time

The other side is dark because there is no light and because there's no light it's night time.

Then it spins around and makes the other part of the earth visible".

Fig. 15.6 Screen capture and transcription of a student's media file recording of their IWB action

Lucy's Narrative Three: Using the IWB to Increase the Modes in which Students Can Demonstrate Understanding.

The students had been talking in small groups about how day and night occur, and so as part of their presentation back to the class, I asked a few students to come up to the IWB to share their ideas. They actually drew on one of the slides in the Spinning in Space notebook, what they thought day and night was and how it happened. But we also used the record function in the IWB software to record exactly what they were drawing and exactly what they were talking about. This was a terrific record of the students learning, the kids have it there, we can show it again and the parents really loved watching it at the school's learning journey evening.

technology and information and communication technologies to enhance the learning process. This involved using the technologies to assist in constructing understanding of science concepts but also for experiencing the explicit modelling of the learning process, in particular, how to critically select and connect to digital sources of relevant information (Fig. 15.6).

The connected nature of the interactive notebooks allowed Lucy and her students to move quickly from one page of the learning experience to another. This allowed the content of the lesson to be easily reviewed or connections to be made to previous activities. Lucy explained how her students used the IWB to share their understanding with the whole class and then to later review their input to the day and night notebook. She said, 'We were using the record function in the notebook software for capturing the children's explanation of night and day as they drew a diagram on the interactive whiteboard'. Recordings were being saved as a media file and later reviewed by the students and Lucy. This interactive pedagogy was extending the options available to students for showing and sharing what they knew about science. Twiner et al. (2010) also recognised that the IWB technology supports a cumulative learning and teaching experience, where the 'improvable objects' in interactive notebooks capture action in the classroom such as sketches, annotations to images and brainstorming notes. This gives a permanence to the talk weaving through learning activities and makes it available for reflection and revision.

15.5.3 Teacher Anthony: Forces in Flight

The IWB notebook *Forces in Flight* was developed by Anthony, a confident user of IWB technology with 2 years' experience. He was a year six (11-year-old) teacher at an independent boys college in an inner suburb of Perth. Anthony was becoming increasingly aware of the impact that IWB technology was having on his planning and structuring of science learning sequences. He stated, 'The IWB notebook provides a direction and a sequence. You are thinking more about your start and end point. You're thinking about what students will connect with, what to do to solidify concepts and where you want to end'. The learning and teaching sequence described here represents two 60-min lessons. These lessons were part of a 12-lesson programme on forces in flight. The learning and teaching purpose of the lessons was to engage the students with an investigation that was relevant to the theme and development of the concepts related to forces in flight. The activities described here fitted within the explain phase of enquiry and moved into the elaboration phase as the students transferred their thinking to a new flight context and carried out an investigation (Fig. 15.7).

Using a range of multimodal representations in the forces notebook focussed student's attention, thinking and talk on the target concept. Anthony's questioning and gesturing assisted his students in the cognitive move between representations and provided opportunities for his students to learn through multiple styles. Anthony explained, 'The IWB moves us away from general paper and pen methods and is getting more of students learning styles into lessons. You've got to show students a concept in different ways, I show videos, animations, diagrams and we talk about it'. The IWB notebook was used to weave together and develop learning. For example, the static images or rockets and aeroplanes were labelled with force terms and directional arrows. These representations were used to focus students' attention on the key concepts and to assist them in moving from the real-life representation observed in videos to the diagrammatic representation which incorporated scientific conventions.

The IWB tools and efficient strategies for linking to the Internet and media files enabled the students to move fluently between everyday and the scientific accounts of phenomena. Jewitt (2006, p. 99) stated, 'The potential to move between these two representations produces a tension between the two views in which each representation

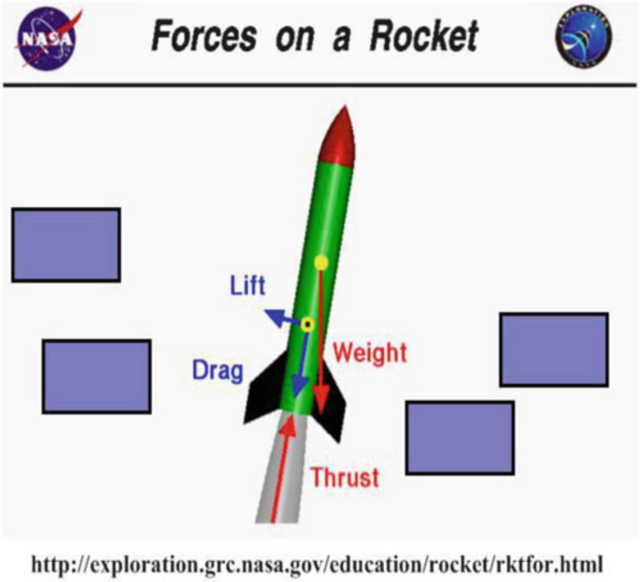


Fig. 15.7 Hide-and-reveal forces in flight

Anthony's Narrative One: Focussing on Key Concepts in Multimodal Representations.

To engage the boys and get them motivated, I showed the video of jet planes in flight that I had embedded in my IWB notebook. I focussed their viewing with the question, what forces of flight help a plane to fly? I used a hide-and-reveal interactive activity to get them thinking about what they had watched and to revise the forces lift, thrust and gravity. Then I got them transferring their thinking to the forces on a rocket. Again, this was a hide-and-reveal interactive task but this time also included directional force arrows.

visually explains the other. This structure demands different things of the students, on the one hand, classification and on the other observation of patterns and the connection of their everyday experiences with scientific theories of phenomena'. The discourse surrounding the teacher and students interaction with the IWB notebook and embedded ICTs was in itself a representation of the science concepts (Murcia and Sheffield 2010). The whole-class discourse and in particular the nature of Anthony's questioning facilitated the students' cognitive negotiation of meaning as they moved from one mode of representation to another. Students learning science have to learn to 'see' scientifically. For example, a student watching an animation of the flow of air over the wing of a jet plane in flight needs to

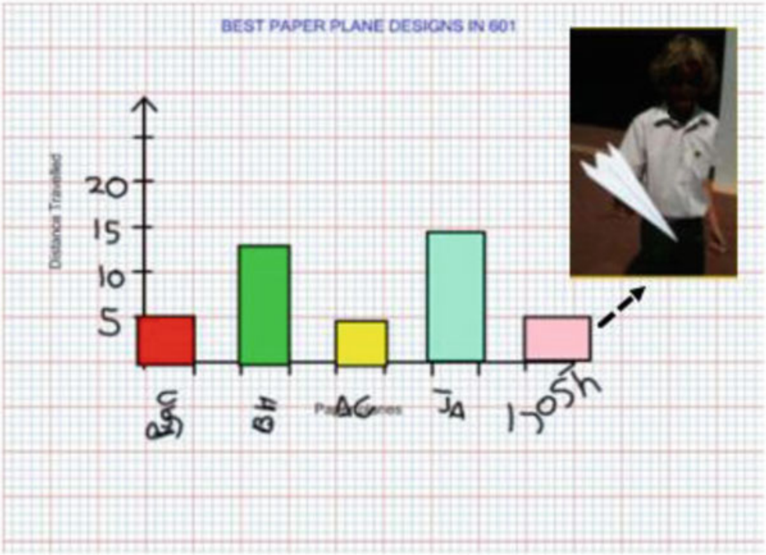


Fig. 15.8 Re-representation of numerical data as a figure

Anthony's Narrative Two: 'Seeing' the Scientific Concepts in Investigation Data.

I used a couple of videos to introduce the investigation task of making and testing a paper airplane and then I used the interactive investigation planner to model for students the planning of a fair test.

The boys made their paper planes and worked in groups to test their designs. I took a photo of the furthest flying plane from each group and then linked each to the student's bar on the whole-class IWB digital graph. I asked the boys to describe the features of each winning paper plane. Because the photos were linked to the bar on the IWB graph, we could move back and forth by just touching the screen. Then to compare all winning paper planes and to find common features, I brought all five photos up on the screen together.

be able to distinguish between the features of a real aircraft and the conventions of scientific images (Fig. 15.8).

Students were given the opportunity to 'see' the scientific principles in an investigation and link these concepts meaningfully from the hands-on investigation to the numerical representation in data, to graphs, to images and written explanations. Time efficient links to multiple IWB notebook pages and multimedia sources extended the modes of representation experienced and assisted in making explicit the translation process between modes. Anthony focused students' attention on the consistent features and dimensions of the concept present in each mode of representation by pointing, gesturing, talking and asking focusing and probing questions.

15.6 Implications for Integrating IWB Use into Science

Opportunities are created for meaning making and conceptual development through the use of multimodal representations in science. In the IWB classroom, the design question is then, what mode of representation will best support students in making meaning or in demonstrating what they know and what pedagogical approach will promote interactive learning? Teachers integrating IWB technology across the curriculum may find this requires some reconfiguring of the physical classroom and rethinking of pedagogy.

First, a shared view of learning should be evident as the central nature of an IWB in the classroom encourages students to present ideas on the social plan and to be active participants in the whole-class learning experience. In the IWB classroom, explicit attention should be given to developing and maintaining a classroom culture which insures an intellectually safe learning environment where students are encouraged to explore ideas in a constructive and cumulative manner. Students should have clear access to the IWB as it is a shared learning resource belonging to all members of the classroom.

Second, building students understanding of science requires a cumulative learning experience, which incorporates modes of representation appropriately matched to the stages of enquiry. In designing IWB learning and teaching experiences, consideration should be given to the following.

- Introductions that aim to engage and elicit students' prior knowledge
- Exploration and explanations which are rich in dialogic discourse about multimodal representations and re-representations of concepts
- Provision of opportunities and high-order questioning, which facilitates students' transferral of their learning to new or different contexts
- Review of learning processes and outcomes

The IWB notebook should be a series of improvable objects that builds the scientific story and captures the learning and teaching through the inclusion of annotations, brainstorming notes and recordings of students' action at the board. Using the interactive whiteboard technology in this manner extends beyond its basic display function and represents pedagogical interactivity.

Teachers are motivated to learn about digital technologies and develop effective interactive pedagogy when they understand how technology such as an IWB can boost their productivity and improve learning opportunities. Ongoing supported professional learning would enable teachers to develop IWB technical skills, resources and pedagogical interactivity. The outcomes of the Edith Cowan University research hub are evidence that effective learning and teaching practice could be developed by teachers as they participated in research. The research was applied and practical with the aim of being responsive to the professional interests and learning needs of the participating teachers. The collaboration with the teachers provided an insight into real classroom practice and enabled researchers to recognise and draw from their classroom-based expertise. The potential benefits of synergies between research and practice were evident in this experience.

In summary, deconstructing and analysing each teacher's video-captured lessons and their IWB notebooks showed that effective interactive pedagogy was dynamic, flexible and multimodal in nature. Teachers' pedagogy was not only focussed on the interactive technology but also on promoting interactive students who actively constructed understanding as they explored science concepts in multimodal formats. Features of the IWB software were used by the teachers to enhance interactivity between themselves, the learning resource and students. They used software tools and design techniques to promote active learning with manipulations such as drag and drop, hide and reveal and layering, colouring, shading and highlighting and annotating with digital ink. The teachers used the IWB to facilitate an ICT rich learning environment and to generate a social learning space that brought the whole class together. They were designing their notebooks in a way that built connections between the interactive activities, tasks at the students' desks and classroom conversations. The notebook shaped and represented the learning journey which supported students' development of the scientific story. Using technology in conjunction with interactive pedagogy, the teachers were able to lead the learning journey, expose students to new ideas, pack and unpack concepts, encourage discussion, challenge preconceptions and build knowledge.

References

Ainsworth, S. (1999). The functions of multiple representations. *Computers in Education, 33*, 131–152.

Australian Academy of Science. (2007). *Primary connections*. http://www.science.org.au/primaryconnections/spinninginspace.htm. Accessed 5 Oct 2009.

Beauchamp, G., & Kennewell, S. (2008). The influence of ICT on the interactivity of teaching. *Education and Information Technologies, 13*, 305–315.

Betcher, C., & Lee, M. (2009). *The interactive whiteboard revolution*. Camberwell: ACER Press.

Deaney, R., Chapman, A., & Hennessy, S. (2009). A case-study of one teacher's use of an interactive whiteboard system to support knowledge co-construction in the history classroom. *Curriculum Journal, 20*(4), 365–387.

Goodrum, D., & Rennie, L. (2007). *Australian school science education: National Action Plan 2008–2012: Vol. 1. The National Action Plan*. Canberra: Department of Education, Training and Youth Affairs.

Hackling, M., & Prain, V. (2005). *Primary connections: Stage 2 trial – Research report*. Canberra: Australian Academy of Science. http://www.science.org.au/primaryconnections/pcreport1.htm

Hackling, M., Smith, P., & Murcia, K. (2010). Talking science: Developing a discourse of inquiry. *Teaching Science, 56*(1), 17–22.

Hand, B., Gunel, M., & Ulu, C. (2009). Sequencing embedded multimodal representations in a writing to learn approach to the teaching of electricity. *Journal of Research in Science Teaching, 46*(3), 225–247.

Higgins, S., Beachamp, G., & Miller, D. (2007). Reviewing the literature on interactive whiteboards. *Learning, Media and Technology, 32*(3), 213–225.

Jewitt, C. (2006). *Technology, literacy, learning*. Oxon: Routledge.

Lee, M. (2010). Interactive whiteboards and schooling: The context. *Technology, Pedagogy and Education, 19*(2), 133–141.

Lemke, J. (1998). *Teaching all the languages of science: Words, symbols, images, and actions*. http://academic.brooklyn.cuny.edu/education/jlemke/papers/barcelon.htm. Accessed 20 Aug 2009.

Littleton, K. (2010). Research into teaching with whole-class interactive technologies: Emergent themes. *Technology, Pedagogy and Education, 19*(2), 285–292.

Mercer, N., Hennessy, S., & Warwick, P. (2010). Using interactive whiteboards to orchestrate classroom dialogue. *Technology, Pedagogy and Education, 19*(2), 195–209.

Murcia, K. (2005). Using action research principles for professional development: The Waikiki school experience. *ALAR Journal, 10*(1), 3–17.

Murcia, K. (2008). Teaching for scientific literacy with an interactive whiteboard. *Teaching Science, 54*(4), 17–21.

Murcia, K. (2010). Multi-modal representations in primary science: What's offered by interactive whiteboard technology? *Teaching Science, 56*(1), 23–29.

Murcia, K., & McKenzie, S. (2008). *Whiteboard Technology: Engaging children with literacy and numeracy rich contexts*. Report to DEEWR Australia. http://www.education.murdoch.edu.au/clcd/docs/Whiteboard%20Technology%20Report.pdf

Murcia, K., & Sheffield, R. (2010). Talking about science in interactive whiteboard classrooms. *Australasian Journal of Educational Technology, 26*(4), 417–431.

Prain, V., & Waldrip, B. (2006). An exploratory study of teachers' and students' use of multimodal representations of concepts in primary science. *International Journal of Science Education, 28*(15), 1843–1866.

Rudd, T. (2007). *Interactive whiteboards in the classroom*. Futurelab. www.futurelab.org.uk/events/listing/whiteboards/report. Accessed 20 Mar 2009.

Tanner, H., Jones, S., Kennewell, S., & Beauchamp, G. (2005, July). Interactive whiteboards and pedagogies of whole class teaching. In P. Clarkson, A. Downton, D. Gronn, M. Horne, A. McDonough & R. Pierce, et al. (Eds.), *Building connections: Theory, research and practice.* Proceedings of the 28th annual conference of the Mathematics Education Research Group of Australasia, Melbourne. Sydney: MERGA. http://www.merga.net.au/documents/RP832005.pdf. Accessed 11 Jan 2011.

Twiner, A., Coffin, C., Littleton, K., & Whitelock, D. (2010). Multimodality, orchestration and participation in the context of classroom use of the interactive whiteboard: A discussion. *Technology, Pedagogy and Education, 19*(2), 211–223.

Tytler, R. (2007). Australian Education Review. *Re-imagining science education: Engaging students in science for Australia's future*. Australian Council for Educational Research.

Tytler, R., Peterson, S., & Prain, V. (2006). Picturing evaporation: Learning science literacy through a particle representation. *Teaching Science, 52*(1), 12–17.

Warwick, P., & Kershner, R. (2006). Is there a picture of beyond? Mind mapping, ICT and collaborative learning in primary science. In P. Warwick, E. Wilson, & M. Winterbottom (Eds.), *Teaching and learning primary science with ICT*. Cambridge: Open University Press/McGraw-Hill House.

Warwick, P., Wilson, E., & Winterbottom, M. (2006). Considering the place of ICT in developing good practice in primary science. In P. Warwick, E. Wilson, & M. Winterbottom (Eds.), *Teaching and learning primary science with ICT*. Cambridge: Open University Press/McGraw-Hill House.

Weinstein, K. (1995). *Action learning*. London: Harper Collins.

Chapter 16

Learning Chemistry Performatively: Epistemological and Pedagogical Bases of Design-for-Learning with Computer and Video Games

Yam San Chee, Kim Chwee Daniel Tan, Ek Ming Tan, and Mingfong Jan

16.1 Introduction

Typical textbooks in chemistry present the field as a fait accompli represented by a body of "proven" facts. For example, a textbook (Heyworth 2002) used in the lower secondary science curriculum in Singapore makes the following claims:

- Atoms are so small that nobody has ever seen a single atom. But *scientists are certain* they exist. (p. 26, italics added)
- *Scientists have discovered* that atoms are made up of three smaller kinds of particles—protons, neutrons and electrons. (p. 32, italics added)
- *It's a Fact!*
  In 1915, Ernest Rutherford fired particles containing protons at some nitrogen gas (atoms of proton number 7). Protons entered the nuclei of the nitrogen atoms and changed them into oxygen atoms (of proton number 8). (Sidebar entry, p. 35, italics added)

The examples above are indicative of the common rhetoric of science that revolves around assertions of fact, scientific discovery, and certainty. Students with the capacity for critical thinking would invariably wonder *why* scientists are so certain of the existence of atoms if no one has ever had the opportunity to see an atom. The textbook author provides no explanation for his existence claim. Student questioning is also not invited. The second example makes use of authorial privilege to assert a claim that atoms, although never ever seen, are composed of protons, neutrons, and electrons. But do scientists merely *discover* this "fact," or is the atom merely a model invented by scientists to help them explain and

---

Y.S. Chee (✉) • K.C.D. Tan • E.M. Tan • M. Jan
Natural Sciences and Science Education, National Institute of Education,
Nanyang Technological University, Singapore
e-mail: yamsan.chee@nie.edu.sg

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_16,

predict chemical phenomena and may not exist at all? The final example appeals to the textbook writer's authority as subject expert to assert a factual claim concerning what Ernest Rutherford succeeded in doing. Why would a thinking student believe such a claim? How would a student even begin to conceive of firing particles containing protons into nitrogen gas? Given the extensive gaps in explanation and credibility, it is hardly surprising that students' mastery of chemistry "facts" through memorization is associated with minimal understanding of the domain and of chemistry processes.

Overall, the presentation style reflected in the textbook is dogmatic, and it does not entertain any form of interrogation or challenge by the student reader. The underlying message is clear: "Do not question; just accept what you are told." In a classroom where the teaching of chemistry is conducted in a traditional manner, teachers further reinforce the image of science as a form of proven dogma. Teachers verbalize and expound the facts. The students' role is to memorize and profess the "right facts." If not, they risk being penalized in their chemistry assessments. Regrettably, students have little, if any, agency to engage in scientific inquiry and to construct their personal understanding of the field. An emphasis on predetermined "knowledge" coupled with the execution of laboratory experiments designed mainly to confirm predetermined "findings" can lead to students leaving school with a grave misunderstanding of the nature of science. Students will not realize that scientists actually require imagination and creativity to invent explanations and models to explain phenomena, and that scientific knowledge is tentative, subject to change, and can never be absolutely proven (Lederman et al. 2002; Schwartz and Lederman 2002). They will also be surprised when they find out that there is competition between rival theories and among "camps" of scientists, that experiment data can be interpreted in more than one way depending on what theory one subscribes to, and that theories can contradict each other (Niaz 2001). These issues are seldom brought up or discussed in class. In general, then, students are not provided with access to authentic science education (Roth 1995). Neither are they helped to understand that engagement in the practice of doing science is the human activity that *creates* knowledge as an ongoing social process of constructing reality (Berger and Luckmann 1966; Knorr-Cetina 1999). The lack of opportunities to directly engage in the practice of doing science lead to outcomes that tend to be wanting: students fail to develop critical problem-solving skills required for conducting scientific investigations, they lack the capacity to interrogate the quality of evidence, and they do not imbibe the dispositions and values that undergird the practice of science. In short, science "knowledge" is mastered at the expense of developing scientific literacy (Murcia 2009). Unsurprisingly, we have witnessed widespread declining interest and participation in compulsory science education that extends beyond school.

In the next section of the chapter, we first share a praxiological framework for human learning that allows us to ground our design-for-learning on the theoretical construct of performance. We then provide readers with a description of what it is like to play level 1 of the game "Legends of Alkhimia." Using the game as a reference point, we next explicate the epistemological and pedagogical bases for the design of a game-based learning curriculum to help students imbibe the thinking, values, and dispositions of professional chemists. The next section considers some challenges of enacting a science inquiry curriculum based on a performance approach to game-based learning, that is, a performance pedagogy. The chapter concludes by summarizing a set of issues that teachers can consider to facilitate the process of change toward adopting a performance pedagogy.

16.2 Praxiological Framework for Studying Human Learning

In constructing the Alkhimia learning environment, our approach to designing the learning process is based on a praxiological framework for studying human learning that is inspired by Collen (2003) who proposed a philosophical foundation that undergirds a general methodology for human systems inquiry. In essence, Collen argues that any comprehensive attempt to study human systems and behavior must subsume three fundamental ideas from Greek philosophy, namely, *ontos*, *logos*, and *praxis*. Together, they yield a praxiology for human inquiry, including inquiry into human learning. Figure 16.1 depicts our appropriation and adaptation of Collen's original idea. This framework allows us to construct an understanding of game-based learning from a process-relational point of view (Chee 2010a; Mesle 2008) that emphasizes the importance of *knowing* through enaction rather than *knowledge* as subject content, whether derived from textbooks, the Internet, or elsewhere. A process-relational approach to understanding human learning foregrounds human *performance*, a term drawn from performance theory (Bell 2008; Carlson 2004) and performance studies (Schechner 2006), and constitutes an onto-epistemological shift to performativity (Barad 2003).

In our design-for-learning with respect to the Alkhimia chemistry curriculum, we deliberately chose to position learning as a form of engagement in human *inquiry* (Dewey 1916/1980; Postman 1995; Postman and Weingartner 1969). We use the term design-for-learning to emphasize the design of an extended learning process based on student engagement in inquiry in contrast to widespread approaches that focus on didactic teaching of subject content. Our praxiological framework allows us to frame learning in terms of human inquiry located in situated contexts. Collen proposed three components of the framework—*ontos*, *logos*, and *praxis*—and we have located the human learner at the center of the interwoven interactions and interdependencies between these three components. *Ontos*, or ontology, is the study of human being, human existence, and of what is. *Logos*, referring to epistemology, is the study of human knowing, what can be known, and what constitutes human knowledge. *Praxis*, or praxiology, is the study of action, the practices of human beings, and of what we (as humans) do. To understand human learning authentically and in all its rich complexity, we deem it vital that learning be studied in the context of humans engaged in situated action, including participation in speech acts and discursive practices that accompany everyday actions (Austin 1975; Bruner 1990; Clancey 1997; Dewey 1938; Gergen 1999). In taking this position, we explicitly

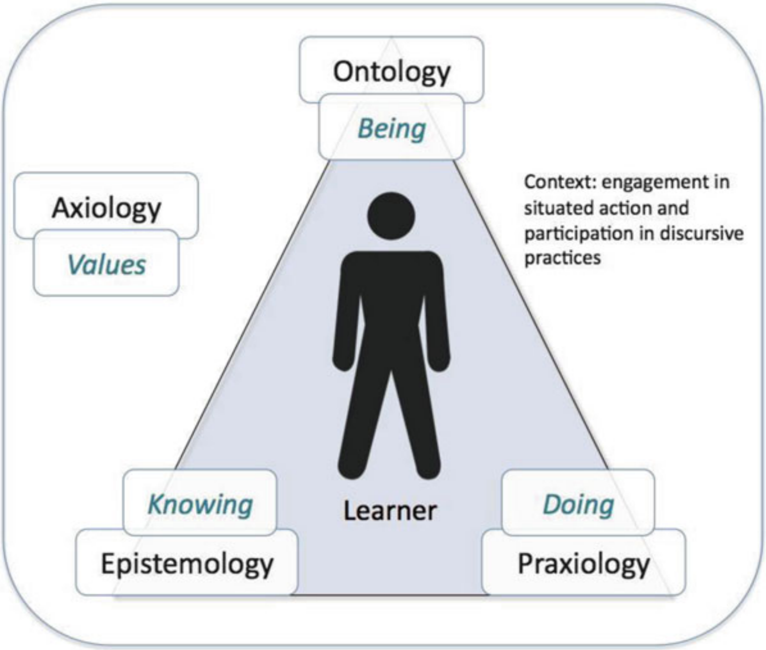


Fig. 16.1 Praxiological framework for studying human learning

reject learning outcomes where students can only talk *about* chemistry, without the ability to engage in the practice of chemistry. The framework in Fig. 16.1 emphasizes that human *knowing* is inseparable from human *doing* (Dewey 1916/1980). But, more than that, it also insists that human knowing and doing are deeply and inextricably intertwined with human *being* (Heidegger 1953/1996). The three elements may be conceived as an interwoven braid whose strength derives from the tight coupling between the components. The framework would not be complete, however, without the addition of a fourth component—values—because knowing, doing, and being are necessarily embedded within a larger sociocultural context of axiology, the study of human *values*. As Ferré (1996, 1998) and Putnam (2002) have argued, knowing, doing, and being are inherently value-laden activities. Humans make basic value distinctions related to all processes and outcomes of learning. These distinctions guide their learning actions toward outcomes that create positive value.

The praxiological framework for studying human learning establishes the foundation for understanding learning in terms of performance, as previously indicated. Central to the idea of performance is engagement in patterned behavior: the doing and redoing of certain identifiable activities, such as the way we present ourselves in everyday life (Goffman 1959). However, a ritualized pattern of behavior constitutes a performance only if there is a self-consciousness, on the part of the person or agent, of the doing and redoing of a pattern of activity. This self-consciousness gives rise to a double consciousness: a person's self-awareness of an actual behavior being enacted that is compared with an ideal intended behavior. Thus, a double consciousness allows the development of reflexivity and the ability of a learner to hold her own actions and behaviors up to personal scrutiny and interrogation (Carlson 2004). This reflexive interrogatory capacity allows the learner to renegotiate the status quo. As performance, learners can then reconstruct and redefine the kind of person they wish to be in relation to the values that they choose to uphold. This process of self-construction is ongoing, and it constitutes the person's trajectory of learning.

Being grounded in part on situated action, our praxiological framework finds resonance with Lave and Wenger's (1991) articulation of situated learning and with situativity theory in general (Barab and Duffy 2000). In the context of game-based learning, our approach, emphasizing embodiment, embeddedness, and experience (Chee 2007), also finds resonance with the work of Barab et al. (2007) with respect to learning with situationally embodied curriculum to achieve transformational play (Barab et al. 2010b). However, there is one critical difference. In adopting a process-relational approach based on process philosophy (Rescher 1996; Whitehead 1978), we hold that there is an inescapable interdependence between epistemology and ontology, giving rise therefore to onto-epistemology as suggested by Barad (2003, 2007). This positioning contrasts with that adopted in classical western philosophy, and apparently adopted by Schuh and Barab (2008), that positions ontology and epistemology independently: "ontology refers to 'what exists' while epistemology is concerned with 'how we come to know about' what exists" (p. 70). The classical positioning assumes that the world can be known objectively. This positioning has been shown to be deeply problematic (Dewey and Bentley 1949; Gergen 1999; Rorty 1979).

Barab and Duffy (2000) make the following claims: "Knowing about refers to an activity—not a thing; knowing about is always contextualized—not abstract; knowing about is reciprocally constructed within the individual-environment interaction—not objectively defined or subjectively created; and knowing about is a functional stance on the interaction—not a 'truth'" (p. 28). We argue that the first three references to "knowing about" are misplaced: they actually refer to "knowing" (as depicted in Fig. 16.1). However, the fourth reference to "knowing about" is appropriate. Furthermore, such "knowing about" is brought forth through language, as part of social participation in discursive practice (Coulter and Sharrock 2007). Failure to distinguish between "knowing" and "knowing about" can readily lead to an unduly high valuation placed on knowledge products: the "content" of knowing about. Thus, while Barab et al. (2010a) foreground intentionality, legitimacy, and consequentiality in transformational play, the focus of investigation is on teaching water quality concepts and using multiuser virtual worlds to support academic content learning. They report their findings in the following terms: "students were clearly engaged, participated in rich scientific discourse, submitted quality work, and learned science content" (Barab et al. 2010c, p. 387). In contrast, the praxiological framework seeks to achieve student learning outcomes defined in terms of an intertwined knowing–doing–being, where articulating conceptual claims constitutes a form of human knowledge representation (Clancey 1997) embedded in discursive practice. Such knowledge representations are always derivative and an outcome of the enactive process of knowing. In short, learning does not begin with knowledge (representations) but rather produces it. The goal of learning, therefore, is to be (a certain kind of person) with a distinct identity through performance. It is not to learn about content as such.

16.3 Learning with the Game "Legends of Alkhimia"

The game "Legends of Alkhimia" (LoA) was designed and developed by our research team at the Learning Sciences Lab, National Institute of Education, to serve as the technology-mediated component of a broader environment for learning chemistry by inquiry in lower secondary school. The learning environment includes not only the game but also associated curricula materials for in-class use that provide the activity structure for student learning activities accompanying game play. The game and materials together constitute the Alkhimia learning program. At the time of writing, the game comprises a six-level multiplayer game that supports four concurrent players. LoA is played over a local area network, typically in a computer laboratory in school. It has been developed to run on PCs.

The game begins in level 1 with a scenario where the four student players crash-land in the vicinity of the ancient town of Alkhimia. While exploring their environs, they are suddenly set upon by a group of fireball-hurling monsters that emerge from a nearby ravine. The players try to repel the monsters with the weapons they are carrying. These weapons, a form of gun, can shoot ammunition drawn from cartridges attached to the weapons. The players find that their weapons are not very effective against the monsters. Furthermore, their weapons frequently jam, making it even more difficult to destroy the monsters (see Fig. 16.2). After a short but furious battle, the monsters retreat into the ravine, leaving the players wondering about the composition of the ammunition in their cartridges and why the ammunition was ineffective in destroying the monsters. This situation establishes context for student engagement in inquiry.

The students receive an instruction from their master, Aurus, via an in-game communication center. He says, "It seems that the mixture you used was not strong enough to destroy the monsters. This could be due to impurities. Proceed to your lab benches to perform separation techniques on the mixture to form new cartridges." Being the first level of the game, this dialog serves to scaffold users with regard to what they might do to begin to solve the problem that they face. The students proceed to their respective virtual lab benches and perform the separation techniques within the game that each thinks will work best. (It should be noted here that the virtual lab bench is implemented with a special software tool that embeds a two-dimensional user interface into a three-dimensional game environment. Consequently, the user is not visible when the lab bench interface is displayed.) Each student chooses what he or she believes is the appropriate purified substance

Weapon Jammed

Fig. 16.2 Players unsuccessfully fending off a monster attack in level 1

to use as ammunition the next time they chance upon the monsters, and they load their cartridge with the chosen substance.

Unknown to the players (but known to us as the designers of the game), the original substance comprises a mixture of acid and sand. A separating funnel (shown in Fig. 16.3) is thus not an effective apparatus for separating the original mixture as this apparatus works only for immiscible liquids. If a player uses the coarse filter paper (item at the top in the apparatus panel on the left), she will obtain two derivative substances, and she can choose to load her weapon cartridge with one of the substances. When the players encounter the monsters a second time in level 1 of the game, they will find that they are no better off than before. If a player uses the separating funnel, the mixture of sand and acid will flow straight through the funnel; hence, their experience in trying to ward off the monsters will be the same as before. If a player uses the substance in the beaker that was derived from mixture separation with the coarse filter paper, she will find that her ammunition is more effective than previously, but her weapon still jams occasionally. However, if the player uses the substance collected in the filter paper as her ammunition (sand), she would find her weapon jamming even more frequently than before. In addition, she will find that her ammunition is largely, but not totally, ineffective against the monster. It is only when a student uses the fine filter paper and she chooses the filtered substance in the beaker as her ammunition that she will experience the greatest success in repelling the attacking monsters (as indicated by the on-screen hit points). In this way, the

Fig. 16.3 A player performing a chemistry separation technique at the laboratory bench

game space allows students to experiment with quite different solution paths and to put different problem-solving solutions to the test in the second battle with the monsters. Thus, the game allows divergent solution paths, and students are not all required to do the same thing at the same time. This design allows for greater personal agency in game play and consequent learning. The vital pedagogical principle in operation here is that the design-for-learning must support meaning making in a relational way. By experimenting with different alternative solutions, some of which work and others do not, students begin to understand why some actions work better than others and why other actions do not work at all. In short, the designed learning experience gives them the opportunity to cite evidence and to provide justifications for what they believe is "right" (i.e., it is a solution that solves the problem) because they have personally experienced how other alternatives fail to solve the problem. Hence, what is "right" is "right" only in relation to all that is "wrong": an important idea drawn from structuralism (Klages 2006).

Assuming that students execute different methods of mixture separation and based on the fact that the associated consequences of those actions will manifest differently in the second encounter with the monsters, the question that students will invariably ask is *why*? For example, why was Peter able to kill the monsters when I was not able to do so?

The cognitive dissonance generated by students' game play transitions into a classroom space of dialogic learning where, under the guidance of a teacher, students learn with one another to construct answers to their pressing questions. This form of dialogic learning can take place first at the student group level, then at the whole class level. In this process, students engage in making sense of their collective game experience. Depending on the time available and on teacher preference, it is also possible to go directly into whole class discussion. In our research experience, we have had occasion to use both. When using the latter arrangement, we place students belonging to the same game play together so that they can speak from a common perspective based on a common game play experience. Students reason to establish what different ammunition effects were observed and then work to identify the causal chain of actions that led to the observed effects. This process requires systematic reasoning that parallels the cycle of scientific inquiry involving questioning, hypothesizing, testing, analyzing, modeling, and evaluating.

As students continue playing "Legends of Alkhimia," the chemistry involved becomes increasingly complex. Like the apprentice scientists that the game positions them to be, they are *required* to develop their own classifications of the substances that they encounter in the game world. They do not experience the world as a prelabeled and a preconfigured place. This deliberate design inducts students into an authentic practice of science making by requiring them to *construct* functional and concise representations and organizations of knowledge. Drawing upon the knowledge constructions of different student groups, the teacher helps students to make critical evaluations about the constructions proposed by different groups. In this manner, students can begin to understand that the construction of scientific knowledge is a social enterprise based on a set of values that esteem explanations that are simple, parsimonious, and generalizable. Students can thus learn to imbibe the values, dispositions, and beliefs that undergird the practice of science making. From the perspective of learning design, we anticipate that learning chemistry in this manner will yield rather different outcomes compared to traditional emphases on content mastery. Given the limits on chapter length and the fact that the focus of this chapter is on design-for-learning, we have deliberately excluded rigorous reporting of empirical findings. Such results can be found in separate publications related to this research project.

16.4 Epistemological Basis of the Learning Design

The epistemological basis of learning with the Alkhimia learning environment is depicted in Fig. 16.4. It shows our performance–play–dialog (PPD) model of game-based learning design (Chee 2010b). This model instantiates a *performance epistemology*. It views knowledge as constituted in action, rather than existing a priori to action, and performance as the activity that allows students to develop competence in the field they are trying to master. By engaging in game play accompanied by speech acts in the form of dialogic conversations (Alexander 2004, 2008; Lemke 1990) that help to make sense of what took place in the game world, students manifest their understanding of chemistry phenomena in the game world of Alkhimia by

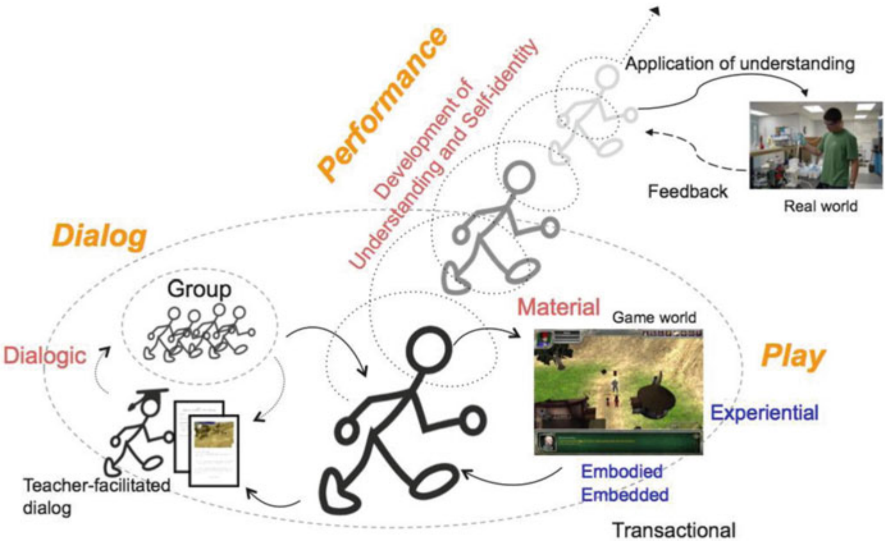


Fig. 16.4 The performance–play–dialog model of game-based learning design

performing (by word and deed) the actions that lead to successful in-game and out-of-game outcomes. Game play (depicted in the lower right corner of Fig. 16.4) takes place in the virtual world of the LoA game; the learning experience is *embodied* through the student's in-game avatar, *embedded* in the game world, and richly *experiential* in nature (Chee 2007).

It is necessary, however, for students to step out of the world of real-time game play and into a dialogic space of conversation where different ideas and viewpoints, or "voices," can interact with one another (Bakhtin 1981). From the Bakhtinian perspective of dialogicality, a voice refers to a "speaking personality." Utterances come into existence through being produced by a voice. As Clark and Holquist (1984) explain: "An utterance, spoken or written, is always expressed from a point of view, which for Bakhtin is a process rather than a location. Utterance is an activity that enacts differences in values." Dialog is thus an activity that creates a space for different student ideas and values to collide and interact with one another. The dialogic process (depicted in the lower left corner of Fig. 16.4) is facilitated by a teacher within a broader context of structured post-game play activities that scaffold students' meaning-making efforts. By engaging in this learning process, students come to understand chemistry performatively.

As shown in Fig. 16.4, as students engage in multiple levels of game play, they iterate over the play–dialog cycle that places them on a forward trajectory of developing competence through performance. Based on the model, they are envisaged to develop a performative capacity to think, talk, and act increasingly like professional chemists. This trajectory of the learning process, projected forward into time, is depicted by images of the student that become more faint as they move upward in Fig. 16.4. Learning in this manner operationalizes the dialectical interplay between first-person learning by doing and third-person learning by thinking/reflection that is key to Dewey's epistemology of learning by doing. In addition, performative learning is characterized by the gradual development of a self-identity that becomes a member of a professional practice community related to the domain, in this context, chemistry. This conception of learning is consistent with Thomas and Brown's (2007) call for student learning to shift away from "learning about" to "learning to be." As an approach to learning that places identity development as a key target outcome, the development of the student's professional identity constitutes a trajectory of becoming (Rogers 1961, 1980). Learning can thus be conceived of as a journey entailing becoming a certain kind of professional person, grounded in a community of practice.

16.5 Pedagogical Basis of the Learning Design

In striving for a chemistry learning environment that can support authentic, disciplinary learning, we have taken professional practice as a basic reference point for our pedagogical method. We seek to foster a form of learning that will enable students to begin to think, feel, and act like professional chemists. Our first level of theoretical reference, therefore, in designing the Alkhimia learning environment, is to the work of Bourdieu (1977, 1998) and to his theory of practice. As a social theorist, Bourdieu wrote extensively about social structures in relation to everyday human practices. A key concept in Bourdieu's discourse of practice is that of *habitus*, which expresses the way in which individuals "become themselves" through the development of attitudes and dispositions related to a professional field on the one hand and the ways in which individuals engage in everyday practices of the field on the other. The notion of habitus mirrors the concept of practical reason (also referred to as practical sense) that refers to a person's ability to understand and negotiate positions within the sites of cultural practice that are comparable to a sportsperson's "feel" for the game (Calhoun 2003). It should be evident from the foregoing that this orientation is praxiological. It is altogether situated in practice and focused on the enaction of behaviors that signify the values associated with a practice. It seeks to help students develop the vocabulary in use, the discourses, and the practices of a professional community, such as that of a scientific community. In short, it helps students to experience what *being* a chemist is like: an orientation that is ontological (see Fig. 16.1).

There is a second level of theoretical reference for our pedagogical design. This level is that of designing for students to participate in scientific inquiry. Like authentic scientists, students engage in "world construction" and meaning-making processes to construct their personal, and justifiable, understanding of the chemistry-related regularities that operate in the game world of "Legends of Alkhimia." The scientific inquiry process involves constructing pertinent questions for inquiry, framing candidate hypotheses that address the questions, engaging in empirical investigations to test the hypotheses, analyzing the data collected from the investigations, constructing an explanatory model of the experience phenomena, and evaluating the robustness of the model.

Fig. 16.5 Class activity of proposing names for game substances as part of the inquiry process

To illustrate one aspect of authentic engagement in scientific inquiry, we draw upon our first in-class enaction of the Alkhimia curriculum in a secondary school in Singapore to provide a concrete example. The participants in our research were 13-year-old students completing the chemistry portion of a general science curriculum that also included physics and biology. As part of our learning design, we asked students to make sense of the nature of in-game chemical substances that they encountered while playing the game. In the out-of-game classroom context, the teacher put up illustrations of the in-game substances introduced in level 1 of the game and invited students to propose suitable names for these substances. Figure 16.5 illustrates this activity in the classroom. It shows how five student groups suggested what they felt would be suitable names for the two substances they encountered in level 1: substance A, a green liquid, and substance B, composed of brown solid particles. As part of the learning process, students were asked to think about the properties of the substances and to provide justifications for why the name they proposed would constitute a "good" name. By facilitating an interrogation of what might constitute a "good" and hence suitable name, the teacher helped students to consider the experienced properties of the substances while playing the game and to relate this experience to naming norms within a scientific community. The latter activity is inherently value-laden because what constitutes a "good" name will vary from one professional community to another. Students were asked to vote on a preferred name so that the game substances could be referred to with unique names when they were encountered again in subsequent levels of the game. Students showed a strong tendency to name the substances based on perceived surface attributes of the substances. As is evident from Fig. 16.5, the names that were agreed on were “squishy liquid” and “dust.”

Returning to the sociology of Bourdieu, our learning design is intended to help students to be reflexive about their own learning and to be critical in interrogating assumptions and biases that may shape the construction of their personal understanding. In this way, students are encouraged to practice epistemological vigilance, so that any social and cultural biases in their thinking can be exposed, queried, and discussed.

In summary, our design-for-learning seeks to address all four aspects of the general framework shown in Fig. 16.1: knowing, doing, being, and values. Student learning is conceived of as knowing that arises from doing within the broader context of being and learning to be, that is, becoming. All of this takes place against the background of a value system associated with the professional community of practice in question.

16.6 Challenges in Enacting Performance Pedagogy

Schoolteachers are faced with significant challenges when they consider the adoption of modes of teaching and learning implied in our pedagogy of game-based learning grounded on the construct of performance. Based on our experience to date working with teachers attempting to enact the Alkhimia curriculum for the first time, we found that they need to adopt a different mind with respect to teaching and learning because our pedagogy embeds deep epistemic change. Adopting this different mind-set, in effect, requires crossing a boundary into a new mode of teaching practice that is based on quite different epistemic assumptions.

We outline below the kinds of challenges that teachers face when contemplating adoption of a performance pedagogy in game-based learning. The distillation of these challenges arises from the conversations that we have had with teachers from two schools collaborating with us to enact the Alkhimia curriculum in their chemistry classes. By identifying the challenges explicitly, we hope that teachers not familiar with the pedagogy can better equip themselves to address the issues they will likely face to successfully enact the pedagogy.

16.6.1 Learning Outcomes and Epistemology

Traditional ways of teaching lower secondary school chemistry focus on students’ mastery of content that arise from didactic teaching on the part of the teacher. We have argued that students’ learning outcomes associated with this mode of teaching are weak because students have no opportunity to engage in the practices of doing science and constructing meaning in science. A performance epistemology values learning outcomes that enable students to enact authentic practices related to the doing of science as part of a broader goal of learning as being and becoming. This orientation represents a fundamental change in student learning goals toward identity development and professional practice. It is based on an epistemology of learning by doing rather than learning by being told.

16.6.2 Curriculum and Assessment

Conventional curricula goals and forms of assessment place great emphasis on students' mastery of subject content. Teachers are concerned that the adoption of game-based learning should not harm traditional content mastery given the same number of teaching hours. While this outcome may be desirable from a pragmatic perspective, it is not likely to hold in practice. Student mastery is likely to correlate highly with what a pedagogy seeks to promote. Thus, teaching for content mastery will lead to student excellence in content mastery, while teaching for performative outcomes will lead to student excellence in performative outcomes.

Teachers are also concerned about modes of student assessment and conforming to standard tests across a class level in school. The modes of student assessment need to be broadened to encompass more qualitative and rubric-based assessments given that outcomes are no longer evaluated purely in terms of getting the answers to standard questions right or wrong.

16.6.3 Concerns Relating to Student Prior Knowledge

Many teachers voice the fear that students will not know how to play the game successfully if they are not first taught the facts of the subject domain. This challenge reflects the difficulty that teachers face in recognizing that from a learning-by-doing perspective, competence is achieved only with performance. That is, students gain performance mastery in the domain through what they do. Distilling the knowledge products of learning is merely a by-product of learning by doing. The promotion of learning by doing does not take place in lieu of learning content. Rather, the latter is ancillary to the former.

16.6.4 School Logistics

The structure of student learning in schools is organized in terms of discrete blocks of time that range from about 35 to 60 min. Enacting a game-based learning curriculum typically requires blocks of approximately 120 min in order for game play and dialogic interaction and reflection to take place without feeling rushed. It is necessary, therefore, for schools to make special arrangements with respect to timetabling in order for a game-based learning curriculum to be enacted.

16.6.5 Sustaining Innovation

Game-based learning, as a pedagogical innovation, takes place within the cultural space of schooling. Our experience working with teachers across multiple schools strongly suggests that schools are inherently culturally bound spaces that are largely resistant to change. As stable systems, school practices have an inherent tendency toward self-perpetuation. Given that game-based learning requires change at a deep, epistemic level, there is often no assurance that a teacher who adopts an innovation will continue with it in future. This challenge is the outcome of deep tensions, and it is not easily resolved because the tension is systemic in nature.

16.7 Conclusion

In this chapter, we have articulated our conception of how lower secondary school chemistry can be enacted with game-based learning. We have argued that traditional ways of teaching chemistry, based on information dissemination and the assertion of scientific truth claims, are weak because this mode of teaching fails to deliver performative learning outcomes on the part of students. In lieu of traditional pedagogy, we have argued, based on a praxiological framework for studying human learning, that learning must address ontological, epistemological, praxiological, and axiological dimensions. Game-based learning, as we have constructed it, allows us to reconceive learning in a way that incorporates the processes of knowing, doing, being, and valuing, processes that we view as vital to an authentic approach to learning.

We elaborated on the epistemological and pedagogical bases of our design-for-learning and explained how learning in the Alkhimia learning environment proceeds. At the time of writing, two curriculum interventions, conducted in separate Singapore schools, have recently been completed. The findings from the empirical work in the classroom will be published elsewhere in due course. We also set out some of the known challenges to boundary crossing facing teachers contemplating the adoption of game-based learning as performance. The distillation of challenges arose from conversations that we had with teachers collaborating with us on the Alkhimia research project.

To conclude, we hope that this chapter helps to inform readers about the vision and opportunities for enhancing pedagogy through a performance approach to game-based learning. We also hope to alert teachers to challenges they may face in adopting this pedagogical innovation.

Acknowledgments The work reported in this chapter was supported by a generous grant from the National Research Foundation, Singapore, under grant number NRF2007-IDM005-MOE-006-CYS. We acknowledge with deep gratitude the contribution of all members of the "Legends of Alkhimia" game design and development team: Rahul Nath, Wee Yik Shan, Ong Cher Yee, Ho Won Kit, Simon Yang, Andy Lim, Henry Kang, and Ittirat Vayachut.

References

Alexander, R. (2004). *Towards dialogic teaching*. Cambridge: Dialogos.

Alexander, R. (2008). *Essays on pedagogy*. London: Routledge.

Austin, J. L. (1975). *How to do things with words* (2nd ed.). Cambridge, MA: MIT Press.

Bakhtin, M. M. (1981). *The dialogic imagination: Four essays*. Austin: University of Texas Press.

Barab, S., & Duffy, T. M. (2000). From practice fields to communities of practice. In D. H. Jonassen & S. M. Land (Eds.), *Theoretical foundations of learning environments* (pp. 25–55). Mahwah: Lawrence Erlbaum.

Barab, S., Zuiker, S., Warren, S., Hickey, D., Ingram-Goble, A., Kwon, E. J., & Herring, S. C. (2007). Situationally embodied curriculum: Relating formalisms and contexts. *Science Education, 91*(5), 750–782.

Barab, S. A., Gresalfi, M., Dodge, T., & Ingram-Goble, A. (2010a). Narratizing disciplines and disciplinizing narratives: Games as 21st century curriculum. *International Journal of Gaming and Computer Mediated Simulations, 2*(1), 17–30.

Barab, S., Gresalfi, M., & Ingram-Goble, A. (2010b). Transformational play: Using games to position person, content, and context. *Educational Researcher, 39*(7), 525–536.

Barab, S. A., Sadler, T. D., Heiselt, C., Hickey, D., & Zuiker, S. (2010c). Relating narrative, inquiry, and inscriptions: Supporting consequential play. *Journal of Science Education and Technology, 19*, 387–407.

Barad, K. (2003). Posthumanist performativity: Toward an understanding of how matter comes to matter. *Signs: Journal of Women in Culture and Society, 28*(3), 801–831.

Barad, K. (2007). *Meeting the universe halfway: Quantum physics and the entanglement of matter and meaning*. Durham: Duke University Press.

Bell, E. (2008). *Theories of performance*. Thousand Oaks: Sage.

Berger, P., & Luckmann, T. (1966). *The social construction of reality: A treatise in the sociology of knowledge*. London: Penguin.

Bourdieu, P. (1977). *Outline of a theory of practice* (R. Nice, Trans.). Cambridge: Cambridge University Press.

Bourdieu, P. (1998). *Practical reason: On the theory of action*. Stanford: Stanford University Press.

Bruner, J. S. (1990). *Acts of meaning*. Cambridge, MA: Harvard University Press.

Calhoun, C. (2003). Pierre Bourdieu. In G. Ritzer (Ed.), *The Blackwell companion to major contemporary social theorists* (pp. 274–309). Malden: Blackwell Publishing.

Carlson, M. (2004). *Performance: A critical introduction*. New York: Routledge.

Chee, Y. S. (2007). Embodiment, embeddedness, and experience: Game-based learning and the construction of identity. *Research and Practice in Technology Enhanced Learning, 2*(1), 3–30.

Chee, Y. S. (2010a). Studying learners and assessing learning: A process-relational perspective on the learning sciences. *Educational Technology, 50*(5), 5–9.

Chee, Y. S. (2010b). *Learning as becoming through performance, play, and dialog, and performance: A model of game-based learning with the game "Legends of Alkhimia*". Manuscript accepted for publication.

Clancey, W. J. (1997). *Situated cognition: On human knowledge and computer representations*. New York: Cambridge University Press.

Clark, K., & Holquist, M. (1984). *Mikhail Bakhtin*. Cambridge, MA: Harvard University Press.

Collen, A. (2003). *Systemic change through praxis and inquiry*. New Brunswick: Transaction Publishers.

Coulter, J., & Sharrock, W. (2007). *Brain, mind, and human behavior in contemporary cognitive science: Critical assessments of the philosophy of psychology*. Lampeter: Edwin Mellen Press.

Dewey, J. (1916/1980). *Democracy and education* (Vol. 9, John Dewey: The middle works, 1899–1924). Carbondale: Southern Illinois University Press.

Dewey, J. (1938). *Experience and education*. New York: Macmillan.

Dewey, J., & Bentley, A. F. (1949). Knowing and the known. In J. A. Boydston (Ed.), *John Dewey: The later works, 1925–1953* (Vol. 16, pp. 1–294). Carbondale: Southern Illinois University Press.

Ferré, F. (1996). *Being and value: Toward a constructive postmodern metaphysics*. New York: SUNY Press.

Ferré, F. (1998). *Knowing and value: Toward a constructive postmodern epistemology*. New York: SUNY Press.

Gergen, K. J. (1999). *An invitation to social construction*. London: Sage.

Goffman, E. (1959). *The presentation of self in everyday life*. New York: Anchor Books.

Heidegger, M. (1953/1996). *Being and time: A translation of Sein und Zeit* (J. Stambaugh, Trans.). New York: SUNY Press.

Heyworth, R. M. (2002). *Explore your world with science discovery 2*. Singapore: Pearson.

Klages, M. (2006). *Literary theory: A guide for the perplexed*. London: Continuum.

Knorr-Cetina, K. (1999). *Epistemic cultures: How the sciences make knowledge*. Cambridge, MA: Harvard University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York: Cambridge University Press.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497–521.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood: Ablex.

Mesle, C. R. (2008). *Process-relational philosophy: An introduction to Alfred North Whitehead*. West Conshohocken: Temple Foundation Press.

Murcia, K. (2009). Re-thinking the development of scientific literacy through a rope metaphor. *Research in Science Education, 39*(2), 215–229.

Niaz, M. (2001). Understanding the nature of science as progressive transitions in heuristic principles. *Science Education, 85*(6), 684–690.

Postman, N. (1995). *The end of education: Redefining the value of school*. New York: Vintage Books.

Postman, N., & Weingartner, C. (1969). *Teaching as a subversive activity*. New York: Dell Publishing.

Putnam, H. (2002). *The collapse of the fact/value dichotomy*. Cambridge, MA: Harvard University Press.

Rescher, N. (1996). *Process metaphysics: An introduction to process philosophy*. New York: SUNY Press.

Rogers, C. R. (1961). *On becoming a person: A therapist's view of psychotherapy*. New York: Houghton Mifflin.

Rogers, C. R. (1980). *A way of being*. New York: Houghton Mifflin.

Rorty, R. (1979). *Philosophy and the mirror of nature*. Princeton: Princeton University Press.

Roth, W. M. (1995). *Authentic school science: Knowing and learning in open-inquiry science laboratories*. Dordrecht: Kluwer Academic Publishers.

Schechner, R. (2006). *Performance studies: An introduction* (2nd ed.). New York: Routledge.

Schuh, K. L., & Barab, S. (2008). Philosophical perspectives. In J. M. Spector, M. D. Merrill, J. van Merriënboer & M. P. Driscoll (Eds.), *Handbook of research on educational communications and technology* (3rd ed., pp. 67–82). New York, NY: Lawrence Erlbaum.

Schwartz, R. S., & Lederman, N. G. (2002). "It's the nature of the beast": The influence of knowledge and intentions on the learning and teaching of the nature of science. *Journal of Research in Science Teaching, 39*(3), 205–236.

Thomas, D., & Brown, J. S. (2007). The play of imagination: Extending the literary mind. *Games and Culture, 2*(2), 149–172.

Whitehead, A. N. (1978). *Process and reality: An essay in cosmology* (corrected ed.). New York: Free Press.

Chapter 17
Challenging Opportunities: Integrating ICT in School Science Education

Julie Crough, Louise Fogg, and Jenni Webber

17.1 Introduction

This chapter details a research and ICT-based initiative that helps bridge an identified gap between science that is conducted in the real world and science education in schools. Section 17.1 outlines the challenges of the problem, the context, the purpose and opportunities of the research initiative. Section 17.2 examines the pathways to resolving the problem including the participatory approaches used throughout the project and the research underpinning the resources that were developed. Section 17.3 discusses the diverging pathways involved in developing and implementing the resources. Section 17.4 reflects on the lessons learnt from the research initiative and identifies some potential future directions.

17.1.1 Challenges for Science Education

In northern Australia, the population density is extremely sparse with an average of 0.3 people per square kilometre who live in an expansive area covering 1.5 million

---

J. Crough (✉)
Research Institute for Environment and Livelihoods, Charles Darwin University,
Darwin, NT 0909, Australia
e-mail: julie.crough@cdu.edu.au

L. Fogg
Northern Territory Department of Education and Training, Curriculum Teaching
and Phases of Learning, GPO Box 4821, Darwin, NT 0801, Australia
e-mail: Louise.Fogg@nt.gov.au

J. Webber
Northern Territory Department of Education and Training,
GPO Box 4821, Darwin, NT 0801, Australia
e-mail: jenni.webber@ntschools.net

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_17,

square kilometres (Garnett et al. 2008; Woinarski et al. 2007). In stark contrast, Singapore has a population density of 6,814 people per square kilometre and a land area of 710.2 square kilometres (Statistics Singapore 2009). Such a sparsely settled region presents considerable challenges where nearly half the schools are located in rural or remote areas, where the teacher retention rates are low, but where challenges for schools in general and science education in particular are high. Other unique demographics that characterise this region create further challenges. In 2007, 39.5% of students enrolled in schools in the jurisdiction of the northern territory (NT) were indigenous, and this percentage is increasing relative to the total student cohort (Department of Education and Training 2008). The Secondary Education Review highlighted the significance of this high proportion of young indigenous people in the NT. In particular, such a demographically young and rapidly expanding indigenous population has responsibility, through the *Aboriginal Land Rights (Northern Territory) Act 1976* for custodianship of 85% of the Northern Territory coastline and half of its land mass. The implications of this for education, and particularly science education for indigenous students, are significant; in order to fulfil responsibilities for 'caring for country', indigenous people will increasingly need to access and engage with Western knowledge systems (Ramsey et al. 2003). Educational technologies provide critical tools for both teachers and students living in these remote areas. For example, the 'schools-of-the-air' that service many remote parts of northern Australia rely on interactive distance learning technologies.

This sparsely settled population of northern Australia lives in a landscape that is dominated by tropical savannas (see Fig. 17.1) covering about 25% of the continent (Hutley and Setterfield 2007). While savanna ecosystems are most commonly associated with the great African plains, with huge herds of animals, they occur in over 20 countries, mainly in the wet-dry tropics (Hutley and Setterfield 2007). Savannas are defined as 'grassy landscapes – woodlands with a grassy ground layer, or grasslands – that occur in tropical areas where the climate is seasonally dry' (Dyer et al. 2001, p. 5). Due to aboriginal occupation for nearly 50,000 years, coupled with relatively recent European settlement in the last 150 years, northern Australia has been bestowed with a great natural legacy where an ecologically functional landscape-scale natural environment has biodiversity of international significance (Woinarski et al. 2007). However, its savanna landscapes are in flux where fire, large grazing animals and invasive species have all been implicated as drivers of adverse change (Woinarski et al. 2007). While this internationally and ecologically significant area includes three World Heritage Areas, Kakadu, Purnulula and Einasleigh, it has remained largely ignored as a focus for quality, web-based and accessible educational resources.

However, many of the challenges facing science education in Australia's savannas are mirrored elsewhere. Science education, not only in Australia but also in many other parts of the world, faces other challenges as political influence intensifies on education and mandated testing (especially in Literacy and Numeracy). Similar concerns for science education are echoed by Rodriguez and Zozakiewicz (2010) who warn that science education is becoming an 'endangered species' in the United States due to the strong emphasis on literacy skills and standardised tests in isolation

Fig. 17.1 Map of Australia's tropical savannas

from specific content areas. While science education faces considerable challenges throughout the world, many of the issues are similar in Australia. In 2001, *The Status and Quality of Teaching and Learning of Science in Australian Schools* identified the need to provide quality curriculum resources for lower secondary teachers and raised the concern of the lack of an interesting, relevant and challenging curriculum that actively engages students (Goodrum et al. 2001). Another study in 2005 commissioned by the Deans of Science found that a large percentage of teachers had not completed a major 3-year undergraduate degree in the science subject for which they were responsible (Fensham 2006). In 2007, Tytler highlighted the mismatch of science that was taught in school with how science exists in the real world (Tytler 2007). Furthermore, Tytler (2007) identified the growing necessity to bridge the gap between scientific research and science education. These issues and concerns are further exacerbated in northern Australia. The need to increase student engagement in science that is relevant and provides a meaningful and contemporary context is a significant challenge particularly in rural and remote areas where there are difficulties securing teachers, let alone qualified science teachers. Access to appropriate curriculum resources that are relevant and current to the environment in which the teachers and students live is also a considerable challenge. Not only has this been a limiting factor for teaching and learning science in remote schools but also for teachers and students in many urban schools.

17.1.2 Opportunities for Science Education

17.1.2.1 New Curriculum Pathways

In response to the aforementioned research and other studies and concerns, the new *Australian Curriculum: Science* has been developed. It focuses on the personal and practical relevance of science to students and addresses contemporary science issues. This gives teachers the basis for teaching science in a way that will engage students in meaningful ways and prepare them to use science in everyday life. The strand *Science as a human endeavour*, a relatively new development for science education in Australia, includes content with a focus on contemporary and future issues relevant to Australian students' lives, for example, sustainability, water in Australia, health, genetics applications, renewable energy, global warming, climate change, technological innovation and engineering (Australian Curriculum Assessment and Reporting Authority 2010). As this new curriculum is implemented throughout Australia, it will become increasingly necessary for teachers to not only integrate this new strand with the other two strands, *Science understanding* and *Science enquiry skills*, but also to ensure that science is relevant and engaging for their students, including studying local contexts where students can make better sense of the ideas to be learnt (Australian Curriculum Assessment and Reporting Authority 2010).

17.1.2.2 Partnership Pathways

In response to such needs at both a national and large regional level, the project – Tropical Savannas Knowledge in Schools – was created to develop relevant, current, interactive and authoritative resources for sustainability in northern Australia. It was the first collaborative online project for the Northern Territory Department of Education and Training (NT DET) as well as the first project between the Tropical Savannas Cooperative Research Centre (TS-CRC) and NT DET. Thus, no models to adopt or adapt were available that could guide the design-based research and resource development. From the outset, however, this research initiative had two key directives from NT DET: it needed to be an online project in terms of outputs (to provide access to all schools, especially those in remote areas) as well as support for the newly implemented outcomes-focused Northern Territory Curriculum Framework. Subsequently, the output of such a collaborative project would be the creative development of a dedicated website for schools. It would be designed with teachers and students, as well as scientific researchers, educational designers and ICT professionals, to address this identified need and help bridge the gap between savanna science and science education in schools.

Cooperative Research Centres (CRCs) are an Australian Government initiative established in 1990 to strengthen collaborative research links between industry, research organisations, educational institutions and relevant government agencies. The Tropical Savannas CRC (TS-CRC), with its 16 partner organisations – including Charles Darwin University – focuses research on sustainable land-management issues in northern Australia. Therefore, through its extensive research partnerships, the TS-CRC provided the opportunities to collaborate with many scientists from disciplines ranging from archaeologists to zoologists.

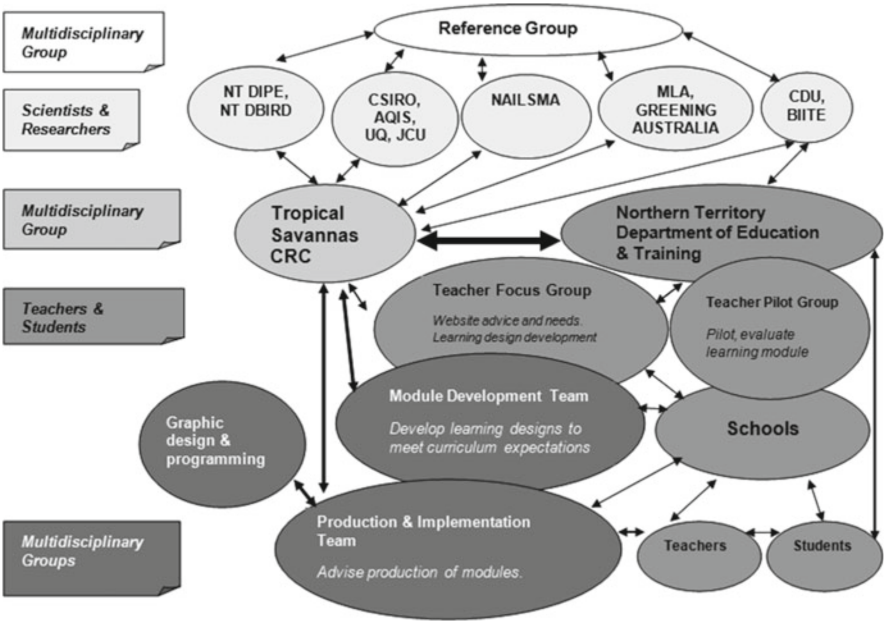
17.2 Converging Pathways: ICT, Science Education and Savanna Science

17.2.1 ICT Affordances

Not only do computer-based learning environments provide access to all schools in the Northern Territory, irrespective of their remoteness, but they also provide an opportunity to adopt different approaches to learning in science education. Research supports that constructivist beliefs are more conducive to technology integration than traditional beliefs. Becker and Ravitz (1999) identify ‘constructivist-compatible’ instructional activities that include: designing activities around teacher and students’ interests; engaging students in collaborative group projects in which skills are taught and practised in context, rather than sequentially; focusing instruction on students’ understandings of complex ideas rather than on definitions and facts; teaching students to self-consciously assess their own understanding; and engaging in learning in front of students, rather than presenting oneself as fully knowledgeable. These constructivist approaches are also supported by research on effective learning that emphasises the following three principles: learning is enhanced when learning opportunities are tailored to an individual’s current levels of readiness; learning is more effective when it leads to deep understandings of subject matter; and learning is more effective when learners are supported to monitor and take responsibility for their learning (Bransford et al. 2000). Thus, it was essential that the ICT resources that were developed for the project needed to embrace constructivist pedagogies.

17.2.2 Participatory Approaches

Collaborative and participatory research methodologies were integral to the design and development of the *EnviroNorth: Living Sustainably in Australia’s Savannas* website.



Acronyms

AQIS -Australian Quarantine Inspection Service
BIITE -Batchelor Institute of Indigenous Tertiary Education
CDU–Charles Darwin University
CSIRO-Commonwealth Scientific Industrial Research Organisation
JCU-James Cook University
MLA-Meat and Livestock Australia
NAILSMA-North Australian Indigenous Land &Sea Management Alliance
NT DIPE, DBIRD-Dept of Infrastructure Planning & Environment,
Department of Busi-ness, Industry & Resource Development
UQ–University of Queensland

Fig. 17.2 Participatory framework for *EnviroNorth* initiative

A framework was developed to facilitate the collaborative and participatory nature of the project (see Fig. 17.2). Small multidisciplinary teams were formed at various junctures in the project. Teachers and students were engaged in the project at various stages including small teacher pilot groups who provided timely and constructive feedback. Scientists and other researchers were engaged in advising the project at strategic points. In particular, their extensive knowledge and experience was sought during the design and development phases of the learning modules and thus embedded in the resources. While key teachers have been involved in the initiative since its inception, they have continued to provide constructive feedback and champion exemplary science education practices in their respective schools and regions. The collaborative nature of the Tropical Savannas CRC facilitated access to both researchers and scientific research in the real world. The overall concept and overarching

Table 17.1 Pedagogical, design and development features of *EnviroNorth* initiative

EnviroNorth	Pedagogical features	Multimodal literacy features	Design and development process
Teach savannas	Curriculum links Teaching for understanding framework Assessment	Scientific articles Graphic organisers Videos Transcripts Templates Field guides	Co-designed with and for teachers, plus ICT professionals
Learn savannas	Enquiry-based Scaffolding Characters/researchers as tutors Concepts interconnected Contextual learning Pedagogical content embedded Multiple perspectives – including indigenous Democratic and prescriptive learning environments Multi-disciplinary Open-ended performance task	Interactive modules integrating: Videos Audio Animation Graphics Artefacts Imagery Simulation	Informant co-design with teachers, students, scientists, graphic artists, programmers and other researchers Research-based design
Savanna windows	Issues-based content Student/teacher guided enquiry Multiple perspectives Cross disciplinary	Subject and geographically based articles Images Graphs	Co-authored with science communicators, scientists and other researchers

website, *EnviroNorth*, drew heavily from ethnography, user observation and user testing approaches to inform its design, structure and development (Futurelab 2004).

17.2.3 Pathways for ICT, Science Education and Savanna Science

The website resources, *EnviroNorth: Living Sustainably in Australia's Savannas*, include three key sections: *Teach Savannas, Learn Savannas* and *Savanna Windows*. Table 17.1 provides a summary of the pedagogical, multimodal literacy features, the design and development process. At the heart of the *EnviroNorth* web site are the interactive multimodal learning modules. These modules support knowledge construction and enable learning (by embedding authentic tasks and resources) that are related to context, to practice (Oliver and Herrington 2001) and to the physical world in which the students live (i.e. northern Australia). The learning modules, *Savanna Walkabout* and *Burning Issues* use an enquiry-based approach to engage students in issues that reflect the challenges of researchers in the real world. These issues focus on biodiversity conservation, environmental management and climate change and sustainable resource use in the tropical savannas. By way of example, Table 17.2 provides a summary of the integrated enquiry, essential questions and learning outcomes for *Savanna Walkabout*. The learning modules, based on learning design, have been co-designed with teachers, researchers and students to represent credible activity and resemble the contexts in which the knowledge that the users are learning can be realistically applied (Herrington et al. 2003).

17.2.3.1 Learning Modules

The learning modules, *Savanna Walkabout*, *Burning Issues* and more recently, *Outback Mobs* were underpinned by current research in educational technology (including: Futurelab 2004; Haughey and Muirhead 2005; Hedberg and Harper 1997; Jonassen 2000; Herrington et al. 2007; Ma and Harmon 2009; McLoughlin and Oliver 2000; Oliver and Herrington, 2001), science and sustainability education (including: Goodrum and Rennie 2007; Tytler 2007; Fensham 2006; Aikenhead 2006; Australian Government Department of the Environment and Heritage 2005; Goodrum et al. 2001) and scientific research conducted in northern Australia (including: Hutley and Setterfield 2007; Woinarski et al. 2007; Whitehead et al. 2005; Dyer et al. 2001).

A modified informant design approach was adopted for the development of each module whereby ‘expert’ informants (researchers, students and teachers) were involved in early co-designing and later tested prototypes in development. For example, with *Burning Issues*, a small group of educators formed the expert informant group to develop the overarching performance task and continued as key co-designers throughout the module’s development. Once a draft prototype was developed, a teacher focus group informed the early design phase. Students were key informants and user-tested an early prototype as well as provided constructive feedback by talking aloud during semi-structured interviews. The development and production were participatory and iterative and at times, messy when numerous iterations were involved particularly during the user-testing and corrections phases. However, these phases were essential in order to ensure that each module’s interface was usable and engaging as well as to maintain the scientific rigour of the content.

Scaffolding, as illustrated in Fig. 17.3, is offered throughout each module using different strategies. Scaffolding includes controlling the focus whereby tutors or experts guide students through explicit questioning or emphasising key ideas or concepts (Bruner 1986). Another form of scaffolding is offered through the student guide in *Burning Issues* (see Fig. 17.3). The guide is accessible throughout the module and helps students formulate their ideas and plan their public awareness campaign. In the guide, a briefing template referred to as ‘My Notes’ acts as part of an online portfolio for students’ ideas and learning so that it can be continually annotated and saved.

Table 17.2 Summary of integrated enquiry, essential questions and learning outcomes for savanna walkabout

		Learning outcomes
Section (enquiry)	Essential questions	Learners
Living savannas (tuning in)	What do we know about tropical savannas?	Reflect on their existing knowledge and understandings of what re tropical savannas Develop understandings of the key characteristics of the tropical savannas biome Understand that unsustainable land use threatens biodiversity in savannas throughout the world
Termite trails	What is the social structure of termite colonies?	Understand that termites (as decomposers and herbivores) play a key role in Australia's savannas
Meet the termites (finding out)	Why are termites the lifeblood of savannas?	Understand that communities of plants, animals and people live and interact in Australia's tropical savanna ecosystems
Interdependence (finding out)	What threatens savannas and people?	Develop skills and understandings to build simple food chains and food webs with real world examples
Impacts (finding out)		Understand some of the key factors – weeds, feral animals and changed fire regimes – that threaten Australia's tropical savanna ecosystems
Research tracks	Who are some of the researchers addressing biodiversity issues in Australia's tropical savannas?	Understand some of the processes as well as the challenges that researchers face as part of working scientifically
Meet the researchers (going further)	What is happening to the Northern Quoll in Kakadu National Park?	Understand that researchers have a major role to play so that well-informed planning and management for biodiversity conservation occurs
Join the researchers (going further)		Participate (through a guided, virtual environment) in exemplary scientific research to overcome current threats to biodiversity in northern Australia Understand that indigenous knowledge and Western scientific knowledge both play a key role in understanding and conserving biodiversity Understand that they can make a difference towards biodiversity conservation and consider how they could get involved in current issues
Savanna treasures (taking action)	What opportunities exist to conserve our biodiversity?	Understand the challenges for biodiversity conservation in the tropical savannas biome Understand that it takes less energy and fewer resources to conserve ecosystems than it does to restore them after significant modification Act individually or as part of a group to make lifestyle choices and take action to protect biodiversity

Hi I'm **Dean Yibarbuk** of the Manwurrk (Bushfire) Rangers located at Kabulwarnamyo on the Arnhem Land plateau.

Explore how we use traditional burning practices and modern science to benefit people and country.

Fig. 17.3 Scaffolding is integral to each learning module such as *Burning Issues*

17.2.3.2 Learning Designs

Learning designs represent a planned set of learning activities, with resources and supports designed to bring about the development of specific knowledge, skills and understandings (Oliver and Herrington 2001). The modules use a learner-centred approach (Sims 2005), where knowledge construction is supported (Haughey and Muirhead 2005) and where technologies support an active, constructive, intentional, complex, contextual, conversational and reflective approach (Jonassen 2000).

17.2.3.3 Authentic Learning Tasks

As part of the learning design, authentic learning tasks and activities need to provide the types of multiple roles and perspectives that are available in real-world challenges. *Learn Savannas* – the home for the learning modules – aims to engage students in science that is relevant to their lives but also the content pedagogy that helps make this possible. For example, in *Join the Researchers*, Dr. John Woinarski tutors students not only through the scientific process but also emphasises the considerations and challenges that are involved with such human endeavours.

Herrington et al. (2007) assert that the affordances of the Internet enable alternative perspectives to be readily accessed and can be targeted for specific tasks. In the context of the existing strong connection of indigenous peoples in northern Australia to their land, wherever appropriate, indigenous perspectives regarding issues were embedded in the modules. For example, the *Savanna Walkabout* module investigates the impacts of weeds on an indigenous homeland – the Rak Mak Mak Marranunggu People and how they have addressed their problem. In the *Burning Issues* module, the role of fire from a range of perspectives, including early European explorers and Traditional Owners, is woven into the module.

17.3 Diverging Pathways: Barriers and Enablers for ICT Integration

17.3.1 Overcoming Barriers

Research and experience has demonstrated that common barriers to technology integration includes lack of infrastructure and practical computer access for teachers and students, lack of teachers' confidence and skills, lack of curriculum freedom to integrate technology, social norms in teaching and learning communities that do not support technology integration, and teachers' pedagogical beliefs that do not align with constructivist pedagogy (Becker and Ravitz 1999; Ertmer 2005). Hedberg (2007) identifies the range of obstacles to integrating ICT including the lack of confidence and/or time for teachers to learn how to integrate ICT in their practices, the lack of ICT infrastructure and support, and the lack of compatibility between traditional teaching practices and constructivist pedagogies partnered by ICT.

The online modules and the whole *EnviroNorth* website were developed to align with the Standard Operating Environment in all NT schools and effort was placed on overcoming barriers wherever possible. For other educators whose system might be different, the Flash plug-in option and link is available with the online modules. As much as possible, any potential infrastructure barriers have been addressed and continue to be revised. For example, teachers in remote schools identified the need for a CD version of the modules to overcome Internet bandwidth constraints and unreliable online facilities. This need was confirmed early in the user-testing phase of *Savanna Walkabout* with CDs subsequently produced and disseminated accordingly.

17.3.2 Creating Enablers

Becker and Ravitz (1999) identify key enablers to technology integration as opinion climate, information and social support resources, and appropriate educational resources in sufficient quantity. Wherever possible, enabling strategies were included in the research initiative. Ethnography, user observation and user-testing approaches with middle-year students and teachers were conducted as part of the needs analysis of the *EnviroNorth* project. Feedback was incorporated into the resources by ensuring that users have the opportunity to explore the democratic learning environment and are actively engaging with it to construct their own understandings.

17.3.3 Integrating Computer-Based Simulations

Computer-based simulations can provide students with opportunities to predict-observe-explain by using phenomena that otherwise would not be available.

Hennessey et al. (2007) recognise the affordances of multimedia simulation that offer dynamic and visual representations of physical phenomena that would otherwise be dangerous, costly or not feasible in a school laboratory. Further, Papadouris et al. (Papadouris et al. 2009) identify the value and role of simulations for students as a powerful tool for exploring, investigating and interpreting natural phenomena. In *Burning Issues*, students 'enter' a virtual world and have the opportunity to manipulate the *Flames* model. In order to guide students in manipulating and understanding the model and its implications for real world situations, a key scientist who developed the *Flames* model, Dr. Adam Liedloff scaffolds the learning process. Ongoing support from Dr. Liedloff is offered via email messages that are generated at appropriate times and pose questions, emphasise key points and explain the more complex concepts.

17.3.4 Applying Web 2.0 Tools

The merits of Web 2.0 tools are evident as they provide particular opportunities to personalise learning for various reasons especially as they enable learners to create their own resources, which also potentially enables increased creativity in the curriculum (Becta 2008). The emergence of Web 2.0 over recent years has provided opportunities to embed Web 2.0 tools into the performance and assessment task in the more recent *Burning Issues* module. As previously mentioned, students are provided with a template *Guide* and teachers are provided with more support tools in the application of Web 2.0 for effective learning in the *Teach Savannas* section. The *Guide* is structured in two sections: *My Notes* provides scaffolding about how students might approach their public awareness campaign, while *My Tools* provides support on some of the Web 2.0 tools learners might like to adopt as part of their campaign. These tools were selected to provide a range of options that align with multiple intelligences (Gardner 1999) and their affordance to enhance learning and creativity.

17.3.5 Providing Learning Supports

A comprehensive teaching guide for each module is provided in the *Teach Savannas* section which includes curriculum links, assessment and learning plan suggestions. For example, *Savanna Walkabout* is fully supported on the *EnviroNorth* website by a suggested learning plan based on the Teaching for Understanding framework (Blythe 1998). Overarching understandings or 'big ideas', understanding goals that identify what students should know and do – the concepts, processes, skills and key questions – all help to focus the teaching/learning programme towards the intended outcomes. The learning plan is designed so that students are actively involved in their learning and continually construct/reconstruct understandings in the light of experience as they move from acquisition of facts to the development of deeper understandings. A metacognitive approach helps learners take control of their learning by defining goals and monitoring their progress in achieving them. The culminating performance task gives students a chance to apply and demonstrate their understandings in a purposeful and contextualised way. This section also includes relevant scientific articles and graphic organisers to support scientific literacy.

The democratic learning environment of each module is flexible enough to meet a diversity of learner needs depending on the learning focus taken and the offline teaching and learning. Some students will thrive in such an environment while others will need more support than is provided within the online environment. Teachers, in the role of facilitators of learning, guide their learners with the process of making meaning. By targeting specific assessment for and as learning opportunities within the module and/or offline to gain and give feedback, teachers can be informed as to what focused teaching or support different learners require. Also, the teaching guide is home to a range of further materials including articles (written in accessible language by the scientists), videos, data sets and graphics. The teaching guide offers a range of teaching and learning options for integrating across learning areas.

17.3.6 Implementing Savanna Science: School Snapshots

Savanna science programmes in schools that incorporate *EnviroNorth* resources and other innovative ICT practices have provided engaging, relevant, meaningful and purposeful learning for students. The following snapshots from a primary school and secondary school provide insights into the potential and realised pathways from integrating ICT in science education with a focus on the *EnviroNorth* resources.

17.3.6.1 Primary School Snapshot

Most children who attend a large primary school, located 40 km south of Darwin situated in a rapidly growing rural area, live on 2-ha blocks and small farms. This rural area is undergoing major change and the population has increased significantly over the past 15 years with the once predominantly savanna landscape now undergoing rapid subdivision into small holdings for residences and micro-agriculture. Environmental and sustainability education is a central part of the school's mission and its curriculum plan. The purpose is to encourage learners to examine and interpret the environment, both locally and globally, from a variety of perspectives; encourage learners to participate actively in resolving problems associated with sustainable development in the students' locality and the development of the school as a sustainable community; give learners 'first-hand' experiences within the environment – the school grounds, the immediate locality and other visits within the region and beyond – and involve learners in finding practical ways of ensuring the caring use of the environment and its resources, now and in the future.

At this school, the *EnviroNorth* website has been identified as a preferred primary resource for the teaching of (and for) the savanna environment and related issues both locally and globally. Since 2007, the resources have been used to support teaching and learning programmes targeting science, studies of society and environment, English, mathematics, learning technology and visual arts learning outcomes. The versatility of the website has allowed for flexibility in the delivery of content and supports a variety of teaching strategies. The resources have afforded a range of opportunities from teaching a comprehensive integrated unit of work that spans a whole semester to taking advantage of discrete sections of the site for targeted teaching.

In primary schools, students have used *Savanna Walkabout's Termite Trails* to prepare oral presentations for both students and parents. This has involved students using programmes such as *Kidspiration*, *PowerPoint* and *Photostory* to plan, construct and represent local savanna food webs. Throughout this process, students sourced suitable images, manipulated and presented information and shared understandings and concerns for savanna ecosystems.

Another integrated programme in the upper primary at this school included culminating tasks that created claymations where students scripted their short films and used webcams to produce the footage. This particular performance task enabled students to use educational technologies to represent their knowledge through narrative writing. These cooperative claymation films not only reflected the depth of the students' understanding about, and for, conserving savanna environments but they also provided students with opportunities to embed field work and investigate ecological and historical aspects of the savannas.

In early childhood at this school, *EnviroNorth* has been used to introduce students to scientists, the scientific method and dispel the myth of the white lab-coated scientist. The interviews with the savanna scientists and the great number of images of scientists in the field (in *Meet the Researchers* section of *Savanna Walkabout*) had most students agreeing that being a scientist out in the 'bush' looked like a lot of fun. Use of this section also provided an engaging way to introduce students to the type of questions that scientists use.

Graphs and data from the Cane Toad (*Bufo marinus*) and Northern Quoll (*Dasyurus hallucatus*) research provided an active way to engage students in data that reflected recent environmental changes in their own backyards. This area of the website – *Join the Researchers* – was chosen by teachers to teach focused lessons on enhancing students' visual literacy skills.

17.3.6.2 Secondary School Snapshot

In a nearby secondary school, also located in a rural setting, most students live on 5-ha blocks usually with stands of natural savanna woodland vegetation. Catering for over 1100 students from Year 7 to Year 12, it incorporates a 75-ha working mixed produce farm in the areas of stock, horticulture and aquaculture and a 150-ha reserve of natural open woodland where students undertake research and practical studies in conservation and land management. A savannas-focused integrated unit of work is introduced at Year 7. The unit aims to engage and connect students with their local environment and incorporates science, studies of society and environment, English and mathematics, building on students' prior learning by utilising the mapping skills developed earlier in the year. Students developed their knowledge and understanding of the adjacent savanna woodland reserve which they had visited earlier in the year. Fieldwork was supported by local government weeds officers who supported both students and teachers in the field. Links with both home and community were achieved through the development and implementation of the students own weed management plan. This process enabled students to take direct action in their own environment by knowing and applying effective weed management strategies.

Both the primary and secondary schools are well resourced with many aspects of ICT in the classrooms including Interactive White Boards and individual computers. However, challenges have arisen with the use of individual PCs in student computer labs. Older computers were very slow and several instances of machines freezing hampered students ability to complete set work in the lesson time available.

17.4 Conclusions and Future Directions

This project's participatory framework and research-based design approach has enabled it to embed pedagogical strategies and practices, partnered with educational technologies, to develop accessible online resources for science education. However, overcoming some of the barriers to effective ICT integration in science education has been a challenge since the *EnviroNorth* website was launched in 2007. As Conole and Fill (2005, p. 5) emphasise, ‘the key to online education and constructivism is not whether or not the potential exists, but rather, whether or not the potential will be actualised’. Actualising such potential, by overcoming barriers to the implementation of these resources, is a challenge. Unfortunately, due to resource shortages (especially people) within the education department and the priority placed on high-stakes testing of literacy and numeracy at a national level the implementation has not been supported at a systemic level. While some infrastructural barriers still exist, they are relatively minor. Confidence and capability in teaching science is still a considerable barrier in many primary, secondary and remote schools in northern Australia where teachers often do not have any tertiary background or experience in science and so are reluctant to take risks and introduce it to their students.

Despite these barriers, *EnviroNorth* has been widely supported not only in northern Australia but throughout the rest of Australia. Evidence from the website usage statistics also suggests that the resources have been used in other countries throughout the world although to a lesser extent. *EnviroNorth* resources have been incorporated in a range of higher education programmes – such as teacher pre-service undergraduate and post-graduate programmes and Vocational Education and Training (VET) programmes. VET in schools is expanding, particularly in remote schools in northern Australia and will be a consideration especially in future. For many indigenous people whose homelands lie in these remote areas, VET is providing pathways for relevant education programmes while completing their schooling.

Experience has demonstrated that supporting teachers with professional learning can be problematic. In northern Australia, not only are there vast distances to cover for teachers to meet for the Science Teachers Association of the Northern Territory, there is also difficulty finding appropriate times. While face-to-face meetings are usually preferable, Web 2.0 tools such as wikis offer greater flexibility for teachers to exchange ideas, experiences and resources irrespective of time and physical location. Such potential opportunities are currently being explored.

The research initiative and resulting suite of website resources, *EnviroNorth: Living Sustainably in Australia's Savannas*, has been successful in achieving its purpose. It is bridging the gap between how science is conducted in the real world in northern Australia and how students conduct science at school. The web-based medium enables new technologies and other initiatives such as the new Australian Curriculum to be integrated into existing resources. The flexibility of such a medium enables new technologies to be accommodated as well as curriculum links and teacher support materials to be easily updated. The research project continues with the next module providing challenging opportunities: how to develop a 'caring for country' module that targets indigenous learners while integrating science, literacy and numeracy.

Acknowledgements This collaborative science education research project involved many other key people including Viki Kane, Peter Gifford, Dr. Peter Jacklyn, Kate O'Donnell, Barbara White, Dr. Linda Ford, Dr. Penny Wurm, Dr. John Woinarski, Dr. Sam Setterfield, Dr. Michael Douglas, Ian Dixon, Dr. Christine Bach, Dr. Ben Hoffmann, Dr. Lindsay Hutley, Leslee Hills, Stephen Sutton, Dean Yibarbuk, Dr. Adam Liedloff, Andrew Turner, Andrew Edwards, Trudi Oxley, Tom Stockwell, Dr. Darrell Lewis, Dr. Gabriel Crowley, Dr. Gordon Duff and Dr. David Garnett. Bushfires NT provided 50% of funding for the *Burning Issues* module. The Tropical Savannas Management CRC funded the project, in collaboration with its 16 partners, including Charles Darwin University.

References

Aikenhead, G. (2006). *Science education for everyday life*. New York: Teachers' College Press.

Australian Curriculum Assessment and Reporting Authority. (2010). *The shape of the Australian curriculum: Science*. Retrieved August 18, 2010, from http://www.acara.edu.au/verve/_resources/Australian_Curriculum_-_Science.pdf

Australian Government Department of the Environment and Heritage. (2005). *Educating for a sustainable future*. Carlton South: Curriculum Corporation.

Becker, H. J., & Ravitz, J. (1999). The influence of computer and internet use on teacher's pedagogical practices and perceptions. *Journal of Research on Computing in Education, 31*(4), 356–384.

Becta. (2008). *Analysis of emerging trends affecting the use of technology in education*. Retrieved August 25, 2010, from http://emergingtechnologies.becta.org.uk/index.php?section=etr&rid=14522

Blythe, T. (1998). *The teaching for understanding guide*. San Francisco: Jossey-Bass.

Bransford, J., Brown, A., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school committee on developments in the science of learning*. Retrieved October 28, 2007, from http://www.newhorizons.org/neuro/neu_review_bransford.htm

Bruner, J. (1986). *Actual minds, possible worlds*. Cambridge, MA: Harvard University Press.

Conole, G., & Fill, K. (2005). A learning design toolkit to create pedagogically effective learning activities. *Journal of Interactive Media in Education, 8*(8), 1–16.

Department of Education and Training. (2008). *Annual report 2008–2009*. Darwin: Northern Territory Government Printers.

Dyer, R., Jacklyn, P., Partridge, I., Russell-Smith, J., & Williams, D. (2001). *Savanna burning*. Darwin: Tropical Savannas CRC.

Ertmer, P. (2005). Teacher pedagogical beliefs: The final frontier in our quest for technology integration? *Educational Technology Research and Development, 53*(4), 25–39.

Fensham, P. (2006). Student interest in science: The problem, possible solutions, and constraints. Plenary address to the ACER Research Conference 2006, "*Boosting science learning – What will it take*?" Canberra.

Futurelab. (2004). *Designing educational technologies with users.* Retrieved September 30, 2009, from http://www.futurelab.org.uk/resources/publications-reports-articles/handbooks/Handbook196

Gardner, H. (1999). *Intelligence reframed: Multiple intelligences for the 21st century*. New York: Basic Books.

Garnett, S., Woinarski, J., Gerritsen, R., & Duff, G. (2008). *Future options for North Australia*. Darwin: Uniprint.

Goodrum, D., & Rennie, L. (2007). *Australian School Science Education: National Action Plan 2008–2012: Vols. 1 & 2. The National Action Plan*. Canberra: Department of Education, Training and Youth Affairs.

Goodrum, D., Hackling, M., & Rennie, L. (2001). *The status and quality of teaching and learning of science in Australian schools: A research report*, Retrieved March 20, 2004, from http://www.detya.gov.au/schools/publications/index.htm

Haughey, M., & Muirhead, B. (2005). The pedagogical and multimedia designs of learning objects for schools. *Australian Journal of Educational Technology, 21*(4), 470–490.

Hedberg, J. G. (2007). Searching for disruptive pedagogies: Matching pedagogies to the technologies. *Curriculum Leadership*, *5*(12). Retrieved August 23, 2010, from http://www.curriculum.edu.au/verve/_resources/Hedberg_Paper.pdf

Hedberg, J., & Harper, B. (1997). *Creating motivating interactive learning environments*. Keynote address at EDMEDIA, Calgary.

Hennessey, S., Wishart, J., Whitelock, D., Deaney, R., Brawn, R., la Velle, L., McFarlane, A., Ruthven, K., & Winterbottom, M. (2007). Pedagogical approaches for technology-integrated science teaching. *Computers in Education, 48*, 137–152.

Herrington, J., Oliver, R., & Reeves, T. C. (2003). Patterns of engagement in authentic learning environments. *Australian Journal of Educational Technology, 19*(1), 59–71.

Herrington, J., Oliver, R., & Herrington, A. (2007). *Authentic learning on the web: Guidelines for course design*. Retrieved October 12, 2009, from http://ro.uow.edu.au/edupapers/48

Hutley, L. B., & Setterfield, S. A. (2007). Savannas. In S. E. Jørgensen (Ed.), *Encyclopaedia of ecology*. Amsterdam: Elsevier.

Jonassen, D. H. (2000). *Computers as Mindtools for schools: Engaging critical thinking*. Columbus: Prentice-Hall.

Ma, Y., & Harmon, S. (2009). A case study of design-based research for creating a vision prototype of a technology-based innovative learning environment. *Journal of Interactive Learning Research, 20*(1), 75–93.

McLoughlin, C., & Oliver, R. (2000). Designing learning environments for cultural inclusivity: A case study of indigenous online learning at tertiary level. *Australian Journal of Educational Technology, 16*(1), 58–72.

Oliver, R., & Herrington, J. (2001). *Teaching and learning online: A beginner's guide to e-learning and e-teaching in higher education*. Perth: Edith Cowan University.

Papadouris, N., Constantinos, P., & Constantinou, T. K. (2009). A methodology for integrating computer-based learning tools in science curricula. *Journal of Curriculum Studies, 41*(4), 521–538.

Ramsey, G., Hill, G., Bin-Sallik, M., Falk, I., Grady, N., Landrigan, M., & Watterston, W. (2003). *Future directions for secondary education in the Northern Territory*. Darwin: Department of Employment, Education and Training. Retrieved October 14, 2009, from http://www.det.nt.gov.au/about-us/publications/secondary-education-review

Rodriguez, A. J., & Zozakiewicz, C. (2010). Facilitating the integration of multiple literacies through science education and learning technologies. In A. J. Rodriguez (Ed.), *Science education as a pathway to teaching language literacy* (pp. 23–45). Rotterdam: Sense Publishers.

Sims, R. (2005). Beyond instructional design: Making learning design a reality. *Journal of Learning Design, 1*(2), 1–8.

Statistics Singapore. (2009). *Statistics Singapore*. Retrieved October 13, 2009, from http://www.singstat.gov.sg/stats/keyind.html

Tytler, R. (2007). *Re-imagining science education: Engaging students in science for Australia's future*. Melbourne: Australian Council for Educational Research.

Whitehead, P., Russell-Smith, J., & Woinarski, J. C. Z. (2005). Fire, landscape heterogeneity and wildlife management in Australia's tropical savannas: Introduction and overview. *Wildlife Research, 32*, 369–375.

Woinarski, J. C. Z., Mackey, B., Nix, B., & Trail, B. (2007). *The nature of Northern Australia: Its natural values, ecological processes and future prospects*. Canberra: Australian National University.

Chapter 18
Science in Early Learning Centres: Satisfying Curiosity, Guided Play or Lost Opportunities?

Elaine Blake and Christine Howitt

18.1 Introduction

With limited research into emergent science skills and a lack of classroom-based research to investigate young children's thinking of scientific concepts (Fleer 2006; Fleer and Robbins 2003; Venville et al. 2003), it is generally unknown how very young children process their scientific curiosity into knowledge. Johnston (2009, p. 2511) explains that important factors affecting the development of scientific skills are found to be in a combination of context and social interactions between individuals, peers and adults. Johnston (2009, p. 2512) also asserts that development of learning specific skills such as observation skills should be supported by focused and structured teaching. Advancing these skills also call on a child's prior experience which are enhanced by using the senses associated with touch, smell, sight, sound and taste. Becoming skilled in observation leads to other scientific skills such as classification, explanation and prediction. By using an integrated curriculum and insightful questioning, educators can present opportunities for children to transform their ideas and rethink what they observe by placing a different perspective on an investigation. New possibilities can be created, and exciting connections made between people and the learning environment when alternative methods of exploring an idea are presented or discovered.

Children, according to O'Sullivan-Smyser (1996, p. 20), are wise about their own learning as they 'seem to know instinctively how to acquire information at a

---

E. Blake (✉)
Science and Mathematics Education Centre, Curtin University, Perth, WA, Australia
e-mail: eblake@iinet.net.au

C. Howitt
Graduate School of Education, The University of Western Australia,
Perth, WA, Australia

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_18,

level that is useful to them'. A major premise to this is an educators' belief that from birth a child is biologically predisposed to relating to and learning from others (Millikin 2003). Therefore, in developing scientific concepts, children often need adult assistance to advance complex thoughts and understand why things are the way they are and why things work the way they do. Young children also require a battery of experiences that allow them to freely explore a concept and move their understandings to more refined knowledge, usually with the assistance of others. What children pay attention to is determined by the environment provided, freedom to explore and what adults or significant others in their company point out to them (Fleer 2007). Steps to encourage and develop scientific thinking should therefore be undertaken by significant others such as teachers, caregivers and parents who have a social and cultural awareness of a child's background and prior learning experiences.

This chapter presents a window into the teaching and learning practices of science concepts for young children in early learning centres, describing both positive experiences and lost opportunities for the development of emergent science skills. The first part of the chapter introduces a socio-cultural context for learning and the notion of a zone of proximal development as a theoretical framework. In the second part of this chapter, the research design and the findings are presented.

18.1.1 A Socio-cultural Context for Learning

Generally, learning environments are made up of social and cultural factors that represent the personal, environmental, interpersonal and contextual influences on a person (Robbins 2005). Children integrate their experiences and curiosity, with the guidance of others, to build new understandings about their world and its workings. Adults who pay attention to how the child's involvement changes and transforms as he or she participates in experiences (Robbins 2005) assist learning and conceptual understanding within a social-cultural context. A social-cultural context recognises prior learning and provides connections and social interaction between individual cognitive thought and actions and those of a group (Venville et al. 2003; Robbins 2005; Fleer and Robbins 2003; Rogoff 2003). The relationship between cognitive and emotional areas of development contributes to and benefits the socio-cultural perspective where social practices rather than individual actions are central to the structure of cognition (Robbins 2005).

The abilities to think logically and sequentially to solve problems in a safe and encouraging environment are essential skills which are honed through engagement with others and opportunities to practise them. 'Thinking is embedded in socio-cultural contexts, and reflects local practices, beliefs, values and goals' (Robbins 2008, p. 27). When teachers are aware of a child's prior learning and include new experiences in a learning environment that could extend their knowledge, an opportunity is provided to make connections between the old and the new knowledge, thus advancing intellect. A child's interpersonal and contextual influences on intellectual learning are clarified and developed when individual thoughts are positively influenced by others in their environment (Robbins 2008). However, cognitive development is not just thinking. It includes a wide range of mental behaviours such as remembering, concentrating, perceiving, reasoning and problem solving (Szarkowicz 2006). Moving a child's conceptual understanding to a new level occurs when he or she is actively engaged and feels confident with new information.

18.1.2 The Zone of Proximal Development

The space between the known and the capability of adding new knowledge is described by Vygotsky (Millikin 2003) as the Zone of Proximal Development (ZPD). Fleer (2006) described this space as 'hypothetical' and elaborated that it is the distance between a child's actual developmental level and their potential level of development. Motivation and social influences by others can assist a child to realise potential. Millikin (2003) concurred that the value and influences of social interaction and feedback from interpersonal and intrapersonal connections advances a child's potential development with the help of adults. Mulaguzzi (1998), however, urges caution with a model where adult intervention is relied upon to develop a child's potential learning. He feels it could result in a return to traditional teaching where words and answers are provided rather than a supportive environment where play, listening and respect for a child's wonder is acknowledged. Robbins (2005, p. 152) supports Mulaguzzi's concern and warns about the dangers of 'preconceived ideas of what children know and can do'.

The aim of teaching, according to Piaget (Mulaguzzi 1998), is to provide conditions for learning that require adults to understand that children are producers, not just consumers, of knowledge and culture. Rinaldi (2005) insists that time and understanding are also essential ingredients for successful learning and adds that adults should only guide a child's learning and ensure enough time is provided to listen to and model effective skills. Rinaldi considers respectful listening skills legitimates another's point of view and can assist a child's understanding of new concepts. Millikin (2003) and Robbins (2005) agree that a socio-cultural context affects the role of the learner and the educator, when children's own questions and theories are thoughtfully considered and negotiated with others. This then supports new learning, consolidates what is known and prepares the child for new experiences. Involvement in investigative events or activities, which move a child from known experiences to new experiences, in an environment where adults assist the advancement of cognitive development rather than providing answers, has the makings of a rich learning environment.

18.1.3 Early Learning Centres

An early learning centre (ELC) is a place where adults and young children come together to exchange knowledge in defined surroundings. These centres can cater for children from birth to 8 years of age and are defined in many ways: child care centres, playgroup, pre-kindy, kindergarten, pre-primary and school years 1–3. A progressive ELC recognises the rights of a child and is attuned to each child's welfare. Simply having aesthetically stimulating environments and educators to provide answers is insufficient in an ELC as children need to be actively engaged in their learning. In a socio-cultural setting where the environment and community are at one with children's needs, adults can provide a semi-structured environment that enables children to communicate, participate and make meaning of their surroundings (Fleer and Robbins 2003). Young children therefore require an ELC where the context is conducive to guided and investigative play and where an interested adult is on hand to assist their constructive thinking so that new concepts are expanded and built upon.

Playgroups serve to connect families within a community. They are informal groups usually led by parents and set up as a community entity, supported by local governments. Attending children are accompanied by an adult (usually a parent or guardian) and meet weekly in a relaxed environment. Children may attend playgroup from birth to 5 years of age with a view of developing social skills, to play and forge friendships.

18.1.4 Research Questions

The following research questions will be addressed in this paper.

1. What opportunities are provided for young children to become engaged in scientific inquiry in early learning centres?
2. In what way do opportunities presented in early learning centres benefit the development of scientific concepts for young children?

18.2 Methodology

The overall purpose of this qualitative research was to gain knowledge of opportunities provided for young children to participate in science in early learning centres. In order to gain this information, a flexible and patient method of inquiry was required to accommodate the unpredictable behaviour that children of this age can present. To achieve this method and generate an understanding of how science is developed and represented in ELCs, a multiple case study research design was used. Multiple case studies allow researchers to better understand the complexity, context and depth of situations, while providing intensive, holistic descriptions and analyses of these situations (Yin 2003).

18.2.1 Settings: Early Learning Centres

Three diverse ELCs were used as the settings for this research. An overview of each ELC can be found in Table 18.1. In each ELC, children directly involved in this research were observed as they engaged in daily activities. Some of the activities were related directly to scientific inquiry. Different physical and institutional teaching and learning contexts were presented in each centre. Two of the three centres (ELC1 and ELC2) were pre-kindergarten classes. These pre-kindergarten classes were attached to larger schools and supported by a Christian religious sector. The third centre (ELC3) was a local government non-sector community playgroup, run by parents. Parents of children in ELC1 and ELC2 contributed fees to the schools so their child(ren) could attend pre-kindergarten. At ELC3, parents contributed to a managed fund that covered the costs of day-to-day running of the centre.

18.2.2 Educators

In each pre-kindergarten (ELC1 and ELC2), a qualified teacher was assisted by a trained education assistant (EA). EAs, under teacher direction, attend to the children's emotional and social needs and assist the preparation of lessons and the classroom. In the playgroup (ELC3), parents help each other in the physical set-up of the learning areas and take responsibility for their own child's welfare.

Teachers (ELC1 and ELC2) were interviewed separately to find whether or not they thought science an important part of the ELC curriculum and to find their levels of confidence and experience in teaching science concepts to young children. Parents were engaged in casual conversations in all three learning centres where their opinion about the value of science teaching and learning was sought.

The teacher in ELC1 was trained to teach at primary school, and her 15 years' teaching experience was mostly in kindergarten and pre-primary classrooms. She was confident to teach science and thoroughly enjoyed teaching young children. Her rich educational background included teaching in Australia and overseas. Currently, she felt restricted by political pressure to 'push-down' the curriculum which she believed would restrict children's time for discovery learning.

The teacher in ELC2 was also trained to teach primary school. In her 12 years of teaching experience, she had taught a number of different primary year levels, five of which were in Year 1 and pre-primary classrooms. This educator's science experience teaching was in primary school years above Year 1. She did not feel confident teaching science and recalled only having learnt how to teach science to upper primary students when at university. She did not specifically seek professional development to teach early childhood science as she did not consider the subject to be an important part of the pre-kindergarten curriculum.

Table 18.1 An overview of the three early learning centres

Description	ELC1	ELC2	ELC3
Institution	Independent PK-Yr 12 school	PK-Yr 6 primary school	Local government community playgroup
Days children attended	4 × ½ days per week	4 × ½ days per week	1 × 2 h per week
School population	>1,000	~250	~19
Group observed and ages	Pre-kindergarten 20 × 3 and 4 year old	Pre-kindergarten 15 × 3 and 4 year old	Playgroup: up to 20 from 3 months to 4-year-olds
Educators	Teacher plus one education assistant	Teacher plus one education assistant	Parents
Training and experience of teacher and education assistant (EA)	Primary trained with ECE units 15 years ECE EA: qualified	Primary trained, some ECE units limited ECE experience EA: qualified	Fully parent-assisted programme No specific training or experience discussed with researcher
Gender	Boys and girls	Boys and girls	Boys and girls
Specific science offered	Daily	Special occasions	Incidental learning
Parent involvement in class	Minimal – could choose to participate on rostered help. Fathers and mothers involved	Invited to start day with child and help him/her settle. Mothers and grandmothers attended. Roster being developed	Total involvement by mothers
Data collection	Fourth term 2008	First term 2009	Third term 2008

ECE early childhood education

Being a playgroup, there was no main teacher in ELC3. A parent, who was trained as an English as a second-language teacher, participated in an interview and suggested that as science was a part of 'nearly everything we do, it should be a part of what the kids do in kindergarten and every other year at school'. Yet, another parent offered that she did not see the relevance in this research as 'these children are too young to do science'. She thought science could be 'dangerous and was really a high school subject'.

As the study progressed, it became clear to the researcher that considering whether or not science was an important part of an ELC was something not previously discussed by any of the centre's communities.

18.2.3 Data Collection

Being thoroughly familiar with the detail of the context in which data would be collected was an essential starting point to find what opportunities were provided for children to become engaged in scientific inquiry and how these opportunities benefited the teaching and learning of science for young children. Each ELC was visited once a week and over the period of one school term, during the centre's morning session. Visits were designed to collect data through conversations with children, parents and teachers; record and conduct casual interviews with teachers; obtain work samples from children; take photographs if permitted; and make field notes of observations so that a clear picture of children's engagement in scientific activities could be formed.

The research was conducted in four stages in each ELC: (1) pre-research, (2) initial visit, (3) subsequent visits and (4) post-data collection. In the pre-research stage, contact was made with each ELC to determine a willingness to participate. Once agreement to participate was attained, approval was sought and gained from the principal of each of the three centres. In the initial visit stage, the researcher discussed details and implications of the research with classroom teachers. Parents were informed and children approached for permission to observe their scientific investigations. Booklets containing ethical implications, information on the research and consent forms, for both teachers and parents, were then delivered to each ELC for signatures of consent. In subsequent visits, the researcher became familiar with the context of the ELC. Interrelationships between children and adults, children and other children were observed and noted along with teachers' and children's interactions with the resources used within the physical and socio-cultural environment. So that children in the centre became familiar with the researcher's presence, a participant-observer role was engaged by joining in activities and, where appropriate, assisting the teacher. This strategy strengthened the relationship within the centre and with children. Planned visits ensured adequate time was available to obtain detailed observations and conversations with children and teachers. Where permitted, photographs and children's drawings were added to data collected. Post-data collection involved a return visit to the ELC to share photographs and initial findings.

18.2.4 Construction and Interpretation of Case Studies

To illustrate the range of science teaching and learning opportunities within the ELCs, three case studies were developed. Each case study was constructed with a general introduction to provide the context, a short vignette to capture the science learning available to the young children and an interpretation. Each vignette incorporated sufficient detail to provide authenticity and captured the action and interaction of the children within their environment in a vivid and life-like manner (Wildy 1999). Interpretation of the vignettes related to the science learning present and opportunities that could have been presented within each ELC.

18.3 Findings

The three case studies entitled *Satisfying curiosity*, *Guided play* and *Lost opportunities* are presented to elaborate findings.

18.3.1 Case Study 1: Satisfying Curiosity

18.3.1.1 Introduction

This case study was taken from the community playgroup (ELC3) and features a three-and-a-half-year-old boy who will be called Skater Boy. Skater Boy is confident in the setting, knows all the parents and children who attend the playgroup and is familiar with its routines and resources. Children in this playgroup are able to play freely and direct their own experiences.

18.3.1.2 Vignette

Skater Boy announced to no one in particular that he was going to make a skateboard. He noticed the researcher was close by and mentioned, without direct contact, his plan to make the skateboard. He collected one rectangular and two cylindrical 3D wooden building blocks from the block box and placed the cylinders under the rectangle. ‘These are rollers’, he said out loud. He tested his design and found the original prototype unsuccessful, so went back to the block collection, found another cylinder and added it to his skateboard (see Fig. 18.1). ‘There’s three now’, Skater Boy said to himself. The new model was tested, but again the result was not acceptable (see Fig. 18.2), so he retrieved more wooden cylinders to act as rollers.

For each new design, Skater Boy patiently added just one more cylinder, counted them (see Fig. 18.3), then tested his skateboard by standing on it. With each trial, the cylinders rolled out from under the rectangle. Skater Boy then moved his testing to include holding onto a cupboard for stability (see Fig. 18.4). During construction, he continually chatted away to himself counting cylinders, planning his next move, testing, thinking out loud and trying to gain balance.

Skater Boy displayed no frustration with the unsuccessful trials but did engage the researcher in his conversation from time to time:

Skater Boy: It’s not working.
Researcher: Why isn’t it working?
Skater Boy: It needs more rollers.
Skater Boy: Look there’s five of ‘em.

Finally, Skater Boy announced, ‘There’s no room left. It’d better work’. Carefully, Skater Boy stood on the rectangle covering the five cylinders, again hanging onto the cupboard to help his balance, he discovered that his construction felt more stable. His smile indicated he was happy with this result. He then let go of the support, bent his knees and momentarily balanced on his skateboard. In a celebratory salute, he held his arms aloft before he felt the skateboard start to topple and had to jump off.

Skater Boy: Did you see? Did you see it? It worked. Good!

Fig. 18.1 Skater Boy modifies the prototype

Fig. 18.2 Testing the new model

Skater Boy then disassembled his skateboard, threw the pieces he had used back in the block box and disappeared into another room without further comment.

18.3.1.3 Interpretation

Skater Boy told the story of his skateboard without prompting, and communicated using egocentric speech or 'self-talk' during the activity. His curiosity had been

Fig. 18.3 Counting extra rollers

Fig. 18.4 Using support during a test

aroused after watching older boys playing with skateboards in a car park. Within his unstructured play space, Skater Boy was able to test his curiosity by designing and making his own version of a skateboard.

Beginning with self interest, Skater Boy constructed a plan in his mind, talked his thoughts through, gathered components, tested his ideas and redesigned them until he was satisfied with the results. Skater Boy had unwittingly used the plan to make, test, appraise scheme of technology development that saw him redesign his skateboard again and again until he was satisfied. Skater Boy was confident that a cylinder would roll but never articulated the name of the shape. And, although he did not use the word ‘balance’ in his dialogue, it was clear he was aware of the scientific concept of balance. This was demonstrated through actions of jumping off the construction when it felt unstable, by recognising a need to hold the cupboard to help adjust stability and by demonstrating balance when he controlled his stance on the construction.

Consolidation and transference of prior learning was demonstrated as Skater Boy included the mathematical concept of one to one correspondence, verbally counting and adding on. Socially, he worked alone. When other children came close, he shielded his work and made it clear (in a non-threatening way) this was his territory. From observed actions, it is suggested that Skater Boy also demonstrated creativity, confidence, concentration, sustained interest and determination as his individual approach satisfied his self-interest and needs at this stage of his development. Had intervention been provided, he may have lost interest or been persuaded to change his plan. Either way, he would not have achieved his personal goal and the obvious satisfaction brought about by achievement. As an unsolicited engineering activity and self-motivated concept, Skater Boy exposed clear thought processes, scientific investigation and concepts of balance. Without assistance, this young boy took himself into a ZPD as he engaged the complex higher-order thinking skills required to modify and retest his design until product satisfaction was achieved. His self-talk helped him plan the sequence of his invention and clarify his ideas. Later in the morning, Skater Boy was noticed building a ramp for his skate board, illustrating that he was once again transferring past learning to that of a new project.

18.3.2 Case Study 2: Guided Play

18.3.2.1 Introduction

The researcher was on her third visit to ELC2, where children had only been attending the centre for 6 weeks. Nature Boy and Nature Girl were the focus of the observations in ELC2. Both children were three and a half years old. Nature Boy and Nature Girl were confident and cooperative children who enjoyed being the centre of attention in the class.

The ELC was set up so that during ‘free-play time’, the children could move about at will, thread beads, do puzzles that were placed on tables or on the floor, colour in pictures and draw on paper. A wooden train set with magnetic points was placed in the middle of the floor with which the children could play. A folding book case housed a selection of picture books in the reading corner. The home corner consisted of a cupboard with cups, tea, coffee, sugar and milk containers, a table and two chairs, a low rail with dress-ups on hangers, some hats and cardboard crowns on top of the hanger and a vase of feathers. Noticeably, there were no curiosity tables containing items of interest to investigate during the first few weeks of the research in ELC2.

During free play, confident children flittered about from table to table, while the more immature children tended to stand and watch other children play. As much as they were encouraged to go to activities, they seemed unsure about what to do and did not spend this free-play time engaged in any activity in depth.

18.3.2.2 Vignette

A table set-up with a variety of natural products, such as various seed pods, leaves, bark and a bird's nest, was added to the classroom for children to freely explore if they wished. When parents arrived at school, they took their children to this new exhibit, modelled curiosity and pointed out features of the leaves and pods to their children. However, nothing was touched. Later, during the free-play time, the researcher stayed at that nature table to encourage investigation. Although children were slightly curious, they were not keen to touch or play with these natural items, which they described as 'dirty' and 'not toys'.

Nature Boy and Nature Girl were invited to participate in a guided investigation of a variety of seeds pods with the researcher, while the other children joined the teacher on the mat. After a discussion about seed pods, the children were encouraged to use their senses to find differences between a gum nut and a pine cone. Nature Boy and Nature Girl participated but showed little initial interest in the objects. Next, it was suggested to sort the seeds pods into two groups: big seed pods and small seed pods (see Fig. 18.5). Once big seed pods were separated from small seed pods according to their own definition of 'small' and 'big', the children were asked to reclassify one of these groups using the same criteria: big and small (see Fig. 18.6).

The children were then left to make their own classifications. Nature Boy decided to put all the pods with 'sharp' edges into a group (see Fig. 18.7), while Nature Girl sorted pine cones from all the other seed pods (see Fig. 18.8).

Rather than returning to the mat for the next session, Nature Boy and Nature Girl remained at the table to continue sorting according to their own rules. With freedom to play, they involved imagination to manipulate objects and extended their classification skills. Nature Boy put leaves end to end to represent the outline of a track for his 'train' to travel along, while Nature Girl imagined palm bark to be a boat and sailed it on an imaginary sea of leaves.

18.3.2.3 Interpretation

As a result of guided play, these children were able to classify objects using observational skills and extended their learning by creating personal classifications and renaming objects that exposed their prior experiences related to trains and boats. Additionally, once the children became 'lost in their play', the researcher noted their actions displayed persistence, humour, curiosity and communication. Nature Boy and Nature Girl had formed a positive relationship as they jointly discussed possibilities and extended knowledge while engaged in 'giggling' play. Confidence and sustained shared thinking were exhibited as they handled and classified the natural objects they had earlier rejected. Adult assistance respectfully supported the children's learning helping them to focus their attention and expose a ZPD. As such, the children extended their ability to stay on task and gain skills of perseverance and concentration enabling them to acquire new knowledge such as that associated with the skill of classification. Guided play helped Nature Boy and Nature girl overcome

Fig. 18.5 Nature Boy compares the size of pods

Fig. 18.6 Nature Girl reclassifies the pods

their initial fear. Offered in a supportive and deliberate way, guidance also encouraged them to solve problems by making critical choices and discover the value of their personal observational skills.

Initially, the young children in this centre displayed shallow engagement as they skimmed the surface of a variety of activities offered to engage their learning. Given they had only been attending ELC2 for 6 weeks, it was not unusual to see some of the children struggling to settle into a routine and become distracted in their new environment. This pre-kindergarten group was unaccustomed to classroom rules, the structure, resources and adults attached to this centre. The children required nurturing, one-on-one attention, small group activities and time to become acquainted with their socio-cultural context before they could comfortably form new relationships

Fig. 18.7 Nature Boy sorts pods with sharp edges from smooth pods

Fig. 18.8 Nature Girl sorts pine cones from other objects

and enhance their academic intelligence. This process was applied with Nature Boy and Nature Girl as they employed a scientific investigation.

According to Fleer (2007), if children are to gain the most of a playful context for learning, they require adult mediation in order to pay attention to the scientific opportunities being offered. Using guided play as pedagogy, the scientific skills of observation, classification, problem solving, creativity and critical choice, considered highly important in emergent science, were well served.

18.3.3 Case Study 3: Lost Opportunities

18.3.3.1 Introduction

A small room within ELC1 had been prepared for this corn-popping experience. All furnishings had been removed, and in the centre of the room an electric fry-pan had been placed in the middle of a circular carpet of paper. Children were assembled as they arrived at school in another area and told about the science investigation. Curiosity was running high as the eager children were given instructions to sit around the edge of the paper and not to touch the cord. The EA was sitting with the pan to ensure children kept a safe distance.

18.3.3.2 Vignette

Once the group was settled, the children were asked about their experiences with pop corn. The teacher initiated questions such as: 'Who has eaten popped corn?' 'How was it cooked?' 'When and where did you eat it?' Responses governed by each child's experience included: 'It cooks in the microwave, in a bag'. 'It stinks'. 'You put butter on to make it taste nice'. 'No, you put salt on it'. 'You eat it when you watch TV'. 'It's white'. 'If you buy it, it's got colours'. 'It's only white'. 'You buy it in a bucket at the movies'.

This prolonged question and answer time provided an opportunity for children to elaborate their past experiences. Each child was given a piece of corn in its seed state to observe. They were then asked to use their five senses to investigate the seed and talk about it with the person sitting next to them. Following this short discussion, the children were told to keep this corn seed because they would need it later for scientific purposes. Selected children then reported their findings to the group regarding the look, smell, sound, feel and taste of the seed. The teacher prompted and insisted on 'full sentence answers'. She also modelled possible responses and congratulated participation.

When the oil in the electric fry-pan was fully heated, seeds were placed into the pan and the heated corn started popping all over the place. Shrieks of joy and laughter filled the room. Exclamations included: 'It's flying!' 'It's shooting!' 'It's going up high'. 'Look! It's on the shelf'. 'Look! It's landed on me'. 'It's snowing everywhere'. Continuous excited chatter and wide-eyed amazement from the children, as the corn popped around the room, made this activity a joy to observe.

The children were then asked to collect one wayward piece of popped corn each and reminded not to eat any. Next, they used their five senses to test the cooked product and talk about their findings with the person sitting next to them. While this conversation happened, the teacher and EA safely removed the pan and oil splattered paper from the floor. As the lesson continued with the teacher, the EA cooked more corn in the kitchen and placed small paper bags of popped corn into each child's locker to take home.

The teacher resettled the children in their semi-circle before asking them for a comparison between the two pieces (uncooked and cooked corn). Comparisons included hard to soft, no smell to good smell, hard to squishy, brown to white and small to big. As before, responses had to be elaborated and questions from the teacher prompted more expansive language. For example, if a child stated, 'It smells different', the teacher would ask, 'What did it smell like before it popped and how is it different now?' Other comparisons from the children included 'The corn was hard before it was cooked and now it is soft' and 'The corn changed from brown to white'.

After the activity, the children were free to play independently in a learning centre of their choice. There was no further follow-up with the popping experience until just before ‘home time’. Once the children were packed up and seated in a ‘sharing circle’, they were asked to recall what they had done that day. The only details about popping corn that the children remembered were the smell, the pieces that ‘flew up high’, and they had some popcorn to take home. The experience and scientific concept of ‘change’ had been largely forgotten.

18.3.3.3 Interpretation

This activity began with such promise yet provided a learning opportunity lost. The children thoroughly enjoyed watching change take place as the corn popped. They enjoyed examining the uncooked and cooked state of the corn, however grew listless when they were not more practically engaged. Sitting in a large group longer than their concentration span and interest allowed did not assist the concept development. Most children were able to report change when questioned during the activity, yet had difficulty recalling scientific details of the experience during the sharing circle time.

Treated as a one-off science activity, little scientific learning occurred as a consequence of not following up the corn activity. Many strategies could have been used to capitalise on the initial excitement and wonder of the children. For example, with assistance from the EA, small groups of children could have cooked their own take-home serve of popcorn. This more intimate experience with the EA could allow the children to talk through their experience, providing an opportunity to ask more questions and consolidate the learning. A free-play learning centre featuring corn could have been established where children could expand their experience with corn. This centre could include a container of corn seeds to play with, plunge hands into, measure, spoon, pour or count. Implements to inspire play, such as containers, a balance and a ladle, would add more learning opportunities. Role playing a piece of corn popping would have personified the change sequence they witnessed. Additionally, photographs could have been taken of the corn popping and, along with comments made by the children, made into a story book. This book would then be used to explain and elaborate the scientific concept of change. Not only was the opportunity to extend scientific understanding of the demonstration lost when the children were not encouraged to discuss related thoughts with an adult, but they were denied a chance to move into a ZPD to actualise potential. These extra strategies would have enabled children to consolidate present knowledge and gain new knowledge while offering rich opportunities for the teacher’s reflections and future planning.

18.4 Conclusion

Each of the three case studies presented offers a different aspect of scientific inquiry by young children, and various pedagogies engaged to deliver those experiences. The richness and appropriateness of staff interactions with children through guiding, modelling and questioning, plus the acceptance of young children's competence and potential are the basis of quality pedagogy (Elliott 2006; Johansson and Emilson 2010). Examples illustrate competence through enabling individual pursuit and interaction in guided play to develop potential, and while the corn-popping experience largely missed the intended scientific concept of change, important questioning skills were developed. Where the pedagogies and experiences related to each scientific inquiry had merit, opportunities for science teaching and learning were lost. For example, a rich opportunity to engage the theory of a ZPD was lost when the corn-popping experience was not extended, whereas children classifying the seed pods were guided to a higher level of engagement and learning by an adult who acknowledged their potential development. Skater Boy, on the other hand, led his own learning to new levels through purposeful play and competence.

Opportunities for educators to gain insight into a child's potential are presented during purposeful play, through responses to open-ended questioning and through discussions during guided play. Actively observing and listening to children as they divulge their interests and knowledge provides a layer of rich information and planning material for the educator (Fleer 2006). This knowledge then directs the establishment of appropriate support, resources and learning centres that offer children science investigations designed to extend their potential cognitive and physical development.

Children are innate explorers and researchers, yet facilitation is required to encourage scientific characteristics and develop sound skills. Johnston (2009, p. 2512) states that the development of good observational skills, for example, needs to be supported by focused teaching. Children are naturally curious. They love to be involved in playful inquiry and have an innate interest in the world in which they live. As such, children are constantly trying to make sense of their everyday experiences and to satisfy their curiosity. The thrill of experiencing popping corn, building a skateboard and being able to create an imaginary train line from leaves are examples of children having a desire to be involved in unravelling the workings of their world and of adults assisting learning. Given the everyday nature of science and the potential of a child, an obvious starting point for planning an integrated curriculum would be based on scientific concepts.

When questioned, teachers' responses about the importance of science teaching and learning varied and did not appear to match the investigations in two ELCs. Where the experience in ELC2 enabled the children to advance their scientific knowledge through hands-on engagement, the experience in ELC1 tended to lose its initial possibilities as children lost interest and no follow-up activities to embed the learning, provided. In contrast, a liberal approach to learning in ELC3 gave children an unstructured environment where they could freely use resources to advance skills according to their own agenda, all the while being encouraged and supported by caregivers.

Having interested adults as active participants in the child's learning environment is essential (Johnston 2009). This role includes actively listening to children's ideas, providing guidance rather than answers, initiating and stimulating talk and modelling how to think things through in a logical sequence. Exciting socio-cultural settings with unimpeded spaces in which a child can wonder about things, chat to others and investigate everyday curiosities can engage their ZPD and thus increase understanding of scientific concepts. This research has found that a balance of planning, flexibility, deliberate teaching and free play is required for a sound platform on which harmonious and positive science learning can occur for young children. Intelligent, thoughtful pedagogy that creates a positive attitude towards science will incorporate meaningful investigations that meet both policy demands and a child's interest whereas over regulated demands and practical constraints will impede learning for young children.

The greatest challenge for early childhood educators is to convince others that play is an integral part of a child's life, even after school has started. Rigorous efforts must be made within the education community to reinforce the value of guided play and intentional, reflective planning for the sound development of scientific skills and concept development in ELCs.

Acknowledgements The children, teachers and parents associated with the three ELCs engaged in this research are sincerely thanked for their willing participation and thoughtful responses to assist the researcher to gather data.

References

Elliott, A. (2006). *Early childhood education: Pathways to quality and equity for all children*. Camberwell: Australian Council for Education Research.

Fleer, M. (2006). "Meaning-making science": Exploring the sociocultural dimensions of early childhood teacher education. In K. Appleton (Ed.), *Elementary science teacher education: International perspectives on contemporary issues and practice* (pp. 107–124). Mahwah: Lawrence Erlbaum Associates.

Fleer, M. (Ed.). (2007). *Children's thinking in science – What does the research tell us?* Watson: Early Childhood Australia.

Fleer, M., & Robbins, J. (2003). "Hit and run research" with "hit and miss" results in early childhood science education. *Research in Science Education, 33*(4), 405–431.

Johansson, E., & Emilson, A. (2010). Toddlers' life in Swedish preschool. *International Journal of Early Education, 42*(2), 165–179.

Johnston, J. S. (2009). What does the skill of observation look like in young children? *International Journal of Science Education, 31*(18), 2511–2525.

Millikin, J. (2003). *Reflections: Reggio Emilia principles within Australian contexts*. Castle Hill: Pademelon Press.

Mulaguzzi, L. (1998). History, ideas and basic philosophy: An interview with Lella Gandidni. In C. Edwards, L. Gandidni, & G. Forman (Eds.), *The hundred languages of children: Advanced reflections*. London: Alex.

O'Sullivan-Smyser, S. (1996). *Professional's guide: Early childhood education*. Sydney: Hawker Brownlow Education.

Rinaldi, C. (2005). *In dialogue with Reggio Emilia: Listening, researching and learning*. London: Routledge Falmer.

Robbins, J. (2005). Brown paper packages: A socio-cultural perspective on young children's ideas in science. *Research in Science Education, 53*(2), 151–172.

Robbins, J. (2008, July). *The mediation of children's thinking about natural phenomena through conversations and drawings.* Paper presented at the thirty-ninth annual conference of the Australasian Science Education Research Association, Brisbane, Queensland.

Rogoff, B. (2003). *The cultural nature of human development*. Oxford, NY: Oxford University Press.

Szarkowicz, D. (2006). *Observations and reflections in childhood*. South Melbourne: Thomson Social Science Press.

Venville, G., Adey, P., Larkin, S., Robertson, A., & Fulham, H. (2003). Fostering thinking through science in the early years of schooling. *International Journal of Science Education, 25*(11), 1313–1331.

Wildy, H. (1999). Statues, lenses and crystals: Looking at qualitative research. *Education Research and Perspectives, 26*(2), 61–72.

Yin, R. K. (2003). *Case study research: Design and method* (3rd ed.). Thousand Oaks: Sage Publications.

Chapter 19
Engaging Children in Learning Ecological Science: Two Botanic Garden Educators' Pedagogical Practices

Junqing Zhai

19.1 Introduction

In recent years, researchers and policy makers around the world have increasingly called for greater attention to be paid to the educational potential of out-of-school settings, citing the many benefits and the necessity of learning in settings other than the classroom. For example, the Manifesto for Learning Outside the Classroom introduced by the British government, encourages schools to provide children with learning opportunities beyond the classroom (DfES 2006). A significant body of research has indicated that school visits to informal settings such as science museums, botanic gardens and zoos are valuable in growing students' understanding of and interest in science (e.g. Malone 2008; Rickinson et al. 2004; Slingsby 2006).

The botanic garden is one of the most popular settings for school excursions. In England, botanic garden educators' lesson for school groups is one of the most important components of botanic garden education (BGEN 2009). Unlike classroom teachers who may lack confidence in teaching beyond the classroom (Glackin 2007; O'Donnell et al. 2006), the botanic garden educators are experienced in delivering outdoor learning activities to different age groups of children. In particular, they effectively offer students an environment that supports inspirational learning about plants and their importance as they serve as the communicators of ecological science and plant conservations to the garden visitors. With respect to school groups, these educators help students to connect their normal daily life experiences to the knowledge about the plants on display in botanic gardens (Sanders 2004). In addition,

---

J. Zhai (✉)
Natural Sciences and Science Education, National Institute of Education,
Nanyang Technological University, Singapore
e-mail: junqing.zhai@nie.edu.sg

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_19,

previous research on education carried out in botanic gardens has suggested that the botanic garden educators fulfill a variety of roles, such as those of 'professional educator, tour guide, and a source of information' (Stewart 2003, p. 354).

To explore the pedagogical practices of the botanic garden educators in England, two research questions guided this study. First, what was the structure of the botanic garden educators' lessons? Second, how did the botanic garden educators support students' learning? The study reported in this chapter has emerged from a doctoral research project and offered a brief picture about botanic garden educators' pedagogical practices.

19.2 Botanic Gardens as Teaching and Learning Environments

Research on museum visitors has suggested that young people's museum visiting experiences have positive impacts on their cognitive, affective, physical, and social development (Anderson et al. Anderson et al. 2003; Falk and Dierking 2000; Hein 1998). The limited literature on learning in botanic gardens has highlighted the importance of early learning experience in forming children's attitudes and active concern for the environment (Bowker 2004; Sanders 2007; Tunnicliffe 2001).

School trips to botanic gardens take place for many reasons (Jones 2000). For many schoolteachers, the most important one is the opportunity to address topics in science and geography curricula. Either often the learning activities organized by schoolteachers or botanic garden educators are focused on investigating plant adaptation, measuring temperature and humidity, and observing plants from all over the world. During the visits, students not only obtain the knowledge regarding science and geography, but also develop their sense of social justice and moral responsibility and begin to understand that their own choices and behaviour can affect local, national and global issues. With respect to this, research has suggested that school trips to botanic gardens should include 'not only knowledge and understanding of animals or plants groups, but also the process of science and general aspects such as care for the environment and communication' (Tunnicliffe 2001, p. 33).

Most school trips to botanic gardens are 1-day trips or just a few hours in duration, and because of this limited period of time the question arises as to how can such a short experience impact on their learning, both cognitively and affectively. In order to discover whether attitudes towards plants can be changed by visiting a botanic garden on a school trip, South (1999) asked elementary students to draw a leaf at the beginning of a visit and again after it. She found that 'there was an increase in the percentage of atypical leaves in the second set of drawings in all the classes' (South 1999, p. 72) which she concluded that the botanic garden visiting experience had expanded students' observational view about plants. From this research, South (1999) suggested that if the botanic garden experience is to produce any significant impact on students' environmental awareness, botanic garden educators need to stimulate student interest by challenging their conceptual thinking.

Similarly, Stewart (2003) has investigated the experience of seven groups of elementary and secondary children aged from 5 to 18 during their school excursion to the Royal Botanic Gardens in Sydney. Both pre- and post-visit interviews with students ($n=50$) were conducted and a survey about their visit experience ($n=284$) was carried out. The author reported that school trips to botanic gardens usually involve two types of learning: learning for cognitive gains and for 'scheme-building' with the former referring to the measurable cognitive outcomes that students can achieve during tightly structured activities such as visits to specific displays to conduct specific tasks, whereas the latter is achieved when students demonstrate long term recall of plants, plant displays and specific locations at a botanic garden. Furthermore, these recollections are linked to specific outcomes sought by the classroom teacher and can contribute to the students' deeper understandings of plants, especially plant structure and biodiversity. Stewart (2003) proposed that practical activities, especially sensory experiences form part of students' long-term recall of their botanic garden experience.

Although botanic garden visiting experiences have a positive impact on students' cognitive learning, some researchers have found that inappropriate teaching may lead to a low level of learning. For example, Bowker (2004) studied a group of 7–11-years-old children who were led by a schoolteacher to the Eden Project in Cornwall. The purpose of his study was to elicit the most effective methods of utilizing a teacher-led school trip so as to enhance children's perceptions of plants and their understanding of people's relationship with them. In total, 72 participating students were interviewed within 1 month of the initial visit and the researcher discovered that they were affected by the sensory experience of being immersed in the garden with such a profusion of plants from around the world. Although most of the students showed an interest in the plants that were relevant to their lives, it emerged that they were often unsure of the relationship between plants, people and resources. In light of this outcome, the researcher contended that to facilitate the understanding of plants and the relationship that human society has with them, it was essential for the educator who is guiding the group during the visit to challenge the students' ideas. This can be achieved by asking 'quality questions that will focus children's attention on important aspects of plants such as plant adaptations to their climate or how people have used and cultivated certain plants' (Bowker 2004, p. 240).

19.3 Research Methods

19.3.1 Research Context

Two botanic gardens, Garden A and Garden B, from two cities in England were selected for this study based on their accessibility, representation of an outdoor classroom in botanic garden settings, and reputation of the education service to the public. Both sites are well-known education institutions in local communities and offer a variety of educational programmes to schools and resources for classroom teachers.

The participating gardens have diverse collections, including plants that live in arid, tropical, and Mediterranean environments.

The education programmes in both sites shared some similarities, and the topics they provided to schools were comparable and consistent with those offered by most botanic gardens in England (Bowker 2002; Sanders 2007; South 1999). The botanic garden educators' lessons observed for this study were pre-planned, one-off lessons to students. The schoolteachers were required to book and prepare the visit in advance. Most teachers selected the topics that the gardens had advertised although sometimes they may have made special requests, such as integrating different subjects into one lesson. As the botanic garden educators explained, each lesson topic was designed in order to suit the requirements stated in the English National Curriculum and the need of the students.

19.3.2 Research Participants

Two botanic garden educators were recruited for this study. By the time of data collection in 2009, Mark had been working as an outdoor educator in Garden A for 15 years. Mark held a BSc degree in ecology, but he had never received formal teacher education. He started his botanic garden educator career after 3 years observing other outdoor educators' teaching. In contrast, Simon, the botanic garden educator from Garden B, was trained to be a teacher as he held a BSc degree in physics and PGCE in secondary science. Prior to becoming a botanic garden educator 6 years ago, he had taught in several urban schools for 20 years.

19.3.3 Data Collection

Before data collection, I spent at least 1 week with Mark and Simon to build rapport and get familiar with their education programmes. Through filed observations and casual talk with the participants, basic information about their background and teaching experiences were obtained. Five lessons led by each educator were observed as initial fieldwork, which provided a brief picture of their teaching procedures and approaches. The data analyzed for this chapter was collected between May and October 2009 (see Table 19.1).

The lessons observed in Garden A were video recorded. I held the camcorder at the back of the class or at the back of the group when they were outside in order to minimize the intrusiveness of the research. The camera always focused on the educator to record discourse and behaviour when he was interacting with students. The camcorder does not work well all the time especially when the educator and students were outdoors due to the noise and movement reduces the video quality, thus I gave the educator an audio-recorder with a clipped microphone to back up the discourse data.

Table 19.1 Details of lesson observed in Garden A and Garden B

	Garden A (Mark)		Garden B (Simon)	
Lesson code	AM-Y5-26/6	AM-Y5-29/6	BS-Y3-07/5	BS-Y3-15/6
Topic	Plants and habitats	Plants and habitats	Plant adaptation	Plant adaptation
Year group	Year 5	Year 5	Year 3	Year 3
No. of students	40	19	19	19
Data type	Audio, video	Audio, video	Audio, note	Audio, note
Length of lesson (minute)	95	94	97	95

Garden B did not give permission to film the visits. Thus, I only used an audio-recorder to capture the discourse between the educator and students. Because the microphone linked to the audio-recorder was clipped on the garden educator's cloth, sometimes it was difficult to hear the recordings from the students who were far away from the educator. As a result, a field note was taken to record students' voices, especially when they were talking to the educator. All the audio-recordings were transcribed verbatim.

The participating educators were interviewed 2 weeks after the lesson observations once I had finished data transcription. During the interview, I showed the educators the transcribed data and audio/video clips to help them to reflect on their teaching practices. The interviews lasted 20–40 min depending on their availability.

19.3.4 Data Analysis

The transcribed interviews were analyzed using open-coding procedures (Strauss and Corbin 1990). The interviews were designed to support the interpretation of botanic garden educators' talk. The combination of educator–student interactions and educator interviews offers a triangulation which enriches the understanding of the teaching and learning practices in botanic gardens. The transcribed discourse data collected from observations were analyzed by applying Mortimer and Scott's (2003) analytical framework, which combines two dimensions of classroom discourse and constructs a matrix that classified the classroom communication into four classes. The four classes of communicative approaches defined by Scott et al. (2006, pp. 612–613) as follows:

- Interactive/dialogic: Teacher and students consider a range of ideas.
- Non-interactive/dialogic: Teacher revisits and summarizes different points of view, either simply listening them or exploring similarities and differences.
- Interactive/authoritative: Teacher focuses on one specific point of view and leads students through a question and answer routine with the aim of establishing and consolidating that point of view.
- Non-interactive/authoritative: Teacher presents a specific point of view.

All the discourse data were analyzed line by line so as to discover the nature of the interaction between the botanic garden educator and students.

19.4 Research Findings

19.4.1 What Was the Structure of the Botanic Garden Educators' Lessons?

Typically, Mark and Simon's lessons involved a structured, narrative-style, and educator-directed experience, in which students and their schoolteachers moved together as a whole group. This finding is consistent with museum docent guided tours to school visiting groups (Cox-Petersen et al. 2003). Both educators appeared to use time well. Mark spent only 9.5% of lesson time in delivering health and safety issues, managing the group, and walking the students from the classroom to glasshouses. The class management time for Simon's lessons was a little longer—11.6% of the whole visiting time—which was, perhaps, due to the fact that the students in his groups were much younger (7 years old) and it would be easier for them to lose their concentration.

The observational data suggests that there is a balance between whole class teaching and students' exploratory work within the 'effective lesson phase' when educators focused on teaching instead of managing the group. Students spent 48% of their time doing exploratory activities in Mark's lessons and 52% in Simon's. It seems that students have sufficient time to discover the garden by themselves as well as listen to the educators' explanations. In this sense, the structure of Simon and Mark's lessons, to a large extent, was educator-directed and student exploratory-based.

The analysis of discourse data has shown that Mark and Simon's talk dominated the lesson discourse, as the student to educator utterance ratio was approximately 1–6. Most of the educators' talk was authoritative/non-interactive in nature and devoted to lecturing type of presentations and demonstrations. Although a relatively large proportion of the educators' talk involved interactions with students (on average, 39% of Mark's talk and 54% of Simon's talk), this interactive discourse was mainly triadic (initiation-response-evaluation) in pattern, which indicates an authoritative role of the educator during the process of exchanging ideas with students. In contrast, the discourse occurred in a chain of interactions (I-R-F-R-F- in pattern), where 'the elaborative feedback from the educator is followed by a further response from the student and so on' (Mortimer and Scott 2003, p. 41) was not broadly observed. In this pattern of discourse, the educator encouraged the students to contribute more to the discussion by engaging them in extended sequences of dialogue. Scott et al. (2006) argued that the dialogic process of and working on ideas has a greater potential to support meaningful learning of disciplinary knowledge. In this regard, Mark and Simon need to further elicit the students' thinking to enable them to articulate, reflect upon and modify their own understanding.

19.4.2 How Did the Botanic Garden Educators Support Students' Learning?

Four prominent teaching strategies that motivate, interest, and support students' learning were found in Mark and Simon's pedagogical practices. These strategies are: (1) using questions to support intellectual engagement; (2) using astounding piece of information to support emotive focus; (3) focusing on learning the language of science; and (4) learning about plants through sensory engagement.

19.4.2.1 Using Questions to Support Intellectual Engagement

Questioning is an effective way to engage students in thinking for understanding (Chin 2007). By analyzing the class discourse, I found that both botanic garden educators preferred to use questions to start their teaching though the amount of questions they asked varied. In the four observed lessons, Mark asked questions 25 times and Simon 102 times.

Mark started his lesson *Plants* by asking 'Did anyone have breakfast?' and then 'Who had plants for breakfast?' The purpose of Mark asking these questions was to check students' understanding about plants. By asking 'Who had plants for breakfast?' 'he cued students' understanding so they could begin to connect plants with food. This question engaged students in thinking about which plants are edible for food. As Mark explained in his interview, the guiding principle for his lesson design was to help children to learn about useful plants, such as those used for food, clothing and medicine. For Mark, connecting teaching and the curriculum with the experiences of learners' home and daily life facilitated the process of meaning making.

Compared to Mark's classes, Simon asked more open-ended questions. Questions such as 'What do the roots do for the plants?', 'What bit of the plant grows up from the roots and reach to the sky?', 'Why do you think flowers have petals?' challenged students' prior knowledge about plants and encouraged them to speculate. These questions provide students with the opportunity to predict, to describe and to explain. The following excerpt is a good example to demonstrate how Simon used questions to support learners' higher-order thinking when teaching plant growth to a group of Year 3 students.

Excerpt 1 The function of roots (BS-Y3-15/6)

Simon: What do the roots do for the plants? What's their job? What do they do?
S4: To make the plants growing bigger.
Simon: They do. I think at the end of Year 3 we need should know exactly what they do to make it grow bigger. What do the roots actually do?
S1: They grow.
Simon: What are they doing when they are growing? They must be doing something. Every part has a job.

(continued)

Excerpt 1 (continued)

9	S6:	When there's the wind it keeps the flower in.
10	Simon:	When the wind blows it keeps the flower in. Good girl. It's quite like
11		that because it anchors down to the ground. If it grows in the soil then
12		the roots anchor that plant down to the ground. So it's very important.
13		This afternoon you may see some roots that do not grow under the ground:
14		some grow in the water maybe and some grow and climb up the walls.
15		So that's one of their important jobs. To hold that plant, to anchor it.
16		What else do the roots do?
17	S7:	They suck the water.

Simon proposed three questions consecutively to challenge students' understanding about the root's function. The first answer 'to make the plants growing bigger' (line 3) is, to some extent, acceptable but Simon has higher expectation from this Year 3 group. Simon prompted the students' idea again by asking 'what do the roots actually do' (lines 4–5) to seek the proper answer to his question. Student 1 answered 'They grow' (line 6), but this is an unclear statement about the function of roots because it could be interpreted as 'the roots help the plant grow' or 'the roots are growing'. This ambiguity might explain why Simon did not comment on S1's answer. Instead, he reformulated the question into 'What are they doing when they are growing?' (lines 7–8) which makes the question easier to understand. 'When there's the wind it keeps the flower in' (line 9), the answer from S6 met Simon's expectation as he repeated that student's answer to confirm her contribution. After explaining how roots anchor the plant, Simon cued students to think about the function of the roots. During the interview, Simon explained why he used the strategy of prompting children by asking questions constantly:

> It's very interesting to listen into the kids talking. It's always very interesting to me. I try to get the chance to listen to the kids because it's obviously they construct information, they have to think. So, one of the big things about visit botanic gardens like this is to give them some spaces to think. (Interview with Simon)

Using questions to engage students in knowledge construction is a popular pedagogical approach adapted by classroom teachers (Chin 2007). The data above suggests that questioning could also be an efficient pedagogical strategy for outdoor educators to engage students in thinking about what they have noticed on the visit and finding connections with their daily life experiences. In short, questions are a key component in teaching-learning discourse which educators from different learning contexts can use as a psychological tool to mediate students' knowledge construction and support them to move towards their 'zone of proximal development' (Vygotsky 1978), which represents current potential learning and leads to new development. To achieve this process, educators need to engage students in student-centred discussions by asking conceptual questions to elicit students' ideas and facilitate productive thinking. The discourse in such a class is educator-led but not educator-dominated and the educator's talk is more like 'talk-scaffolding' (Westgate and Hughes 1997) rather than knowledge transmission.

19.4.2.2 Using Astounding Piece of Information to Support Emotive Focus

Research carried out in museums has suggested that affective talk is a common behaviour for visitors to use to express their pleasure, displeasure or surprise about the exhibition (Allen 2002). The plant kingdom is a world full of exotic things for people to discover. On a school excursion to a botanic garden, students can get access to the exotic part of the natural world and experience different living environments which may affect their emotions and feelings. As Carson (1998) suggested, feelings towards the natural world are antecedents to intellectual growth:

> Once the emotions have been aroused—a sense of the beautiful, the excitement of the new and the unknown, a feeling of sympathy, pity, admiration or love—then we wish for knowledge about the object of our emotional response. Once found, it has lasting meaning. (p. 56)

The astounding piece of information is powerful motivation and stimuli for learning and development. It is more than factual information. It could provide students with long-term memories and facilitate situational interest being developed into personal interest, which may engage them in learning ecological science to a higher level (Hidi and Renninger 2006).

Young people are normally interested in watching, hearing and talking about wild facts. Mark, the educator from Garden A, thought that talking about an astounding piece of information to students was a part of his ideal lesson. The following two excerpts illustrate how Mark supported the student emotional engagement.

When Mark was teaching about living habitats to a group of Year 5 students, he showed them the living creatures in the pond water through a microscope (see Excerpt 2). When he magnified the image, the cell-shaped moving creatures surprised students. It turned out that those students had never thought pond water harboured many tiny animals. During lunchtime, a student reminded his partners to wash their hands by referring to the scenario of moving cells.

Excerpt 2 Pond lives under microscope (AM-Y5-26/6)

Mark: What I've done is put four drops of it underneath the microscope here and that's on what you can see through the screen. These are tiny creatures they are living there. This is their home. [Mark adjusted the microscope to enlarge the image the screen]
Mark: What you see now is magnified by 650 times.
Mark: [Many living creatures showed up on the screen] If I zoom it in, it is magnified by 1,500 times.
Ss: [There are some cell live things are moving around on the screen] Whoa.

In another Year 5 class, Mark presented the biggest and smallest seed in the world (see Excerpt 3). Students were amazed by seeing the real object and were surprised by getting the information that the smallest seed can weigh only one thousandth of a gram. When I contacted the class teacher of the Year 5 group 2 weeks after the visit, the teacher told me that students talked a lot about seeds dispersal when they went back school.

Excerpt 3 The giant Coco de Mer (AM-Y5-29/6)

Mark: [Mark put a Coco de Mer on the table] It is a double coconut. It's the heaviest seed in the world.
Ss: Whoa.
S7: It's so big.
Mark: The heaviest one in the world, bear in mind it is a seed, I heard is 22 kilo grams.
Mark: [Mark showed students a Petri dish with orchid seeds in] These are the seeds from a type of plant called orchid, its actual name is Vanda. These are so small they might even be floating in the air around us right now. They weigh one thousandth of a gram.
S3: Seriously?
Mark: Yes.

Another example of using astounding piece of information to support emotive focus was when Mark explained how Venus flytraps capture insects to get minerals for living to a group of Year 5 students. Some of the students used their hands to model how a Venus flytrap trapped insects, which indicates that they were engaged in learning how carnivorous plants are adapted to a wet and poor soil environment.

19.4.2.3 Focusing on Learning the Language of Science

Science is rich in words and terms. Wellington and Osborne (2001) suggested that learning the language of science is a major part of science education. In the 1998 National Curriculum for England, there was a section on the use of language across the curriculum which requires teachers to teach students to 'use language precisely and cogently' when talking about science (DfEE 1999, p. 69). The 2008 National Curriculum continues this focus, which suggested that the development of essential literacy skills, through discussion and the use of scientific vocabulary and terminology as one of educational aims of secondary science curricula (QCDA 2008). School trips to botanic gardens offer an excellent opportunity for students to develop the language of science.

The students taught by Simon were from inner city schools where a large proportion of the children do not have English as a home language. To help these students to develop their communication skills was an important task for Simon. What he focused on during his teaching was to facilitate students by using proper words to describe plants, and he stated this as his educational goal to the students and class teachers at the very beginning of his lesson. During the course of the lesson, Simon reminded the students several times to use the scientific words to describe plants. For instance, when a Year 3 boy referred to 'roots' and 'leaves' as 'the bottom bit' and 'the green bit', Simon asked the whole class to repeat the correct words to describe those specific parts of a plant.

The next excerpt shows how the language of science was taught to the students in some detail. Before getting into the acid glasshouse, Simon demonstrated to the students how to read the mark on a thermometer by using the science word ‘Celsius’. Excerpt 4 was taken from the teaching session in the acid glasshouse where students were requested to find the temperature of the room by themselves. Simon checked a student’s fieldwork and asked her about the reading on the thermometer. The girl gave the answer immediately, but she only reported the number showed on the equipment. Because her answer ‘18’ did not make any sense, Simon told her the answer should be ‘18 Celsius’. Simon gave a daily life example to help students to understand that a unit can make sense of the number (lines 5–6). This case highlights the importance of teaching children the meaning of science words rather than simply giving the words themselves. Children’s understanding of words can be developed through appropriate teaching and authentic real world experiences (Wellington and Ireson 2008).

Excerpt 4 The Celsius scale of temperature (BS-Y3-07/5)

1	Simon:	What temperature is it?
2	S9:	18
3	Simon:	18 Celsius
4	S9:	Celsius
5	Simon:	Remember to put a unit. Ok? If you go to a shop somebody doesn’t say 18 but
6		they say 18 pence or 18 pounds, so we have to say 18 Celsius

Teaching children the language of science is a big challenge for botanic garden educators. Simon complained, during the interview, according to his working experience in mainstream schools and local education authority, that the schoolteachers seldom focus their teaching goals on the development of children’s language. So a challenge for botanic garden educator is to teach proper science words to young children, especially those whose first language is not English.

19.4.2.4 Learning About Plants Through Sensory Engagement

According to Vygotsky (1978), ‘children solve practical tasks with the help of their speech as well as their eyes and hands’ (p. 26). Children can not only develop their language of ecological science on a botanic garden visit, but also the direct interactions with plants may increase their interest in plants and attitudes to appreciate the wonder of nature. It is important for students to be able to see, hear, touch, smell and live the experience during the visit (Ballantyne and Packer 2009). However, the health and safety concerns are the barriers for them to be encouraged to interact with plants through their multisensory modalities. Botanic garden educators usually have enough knowledge of botany to know which plants are harmful for touching, smelling, or tasting. They can guide the students in a safe way to interact with plants by touching or smelling them.

Collecting specimens was an important method for Darwin to develop his famous theory of natural selection (Kohn 2008). Botanic garden educators have designed various hands-on activities to support their young visitors’ interaction with plant artifices. In Garden A, students were encouraged to collect leaves, flowers, and feathers

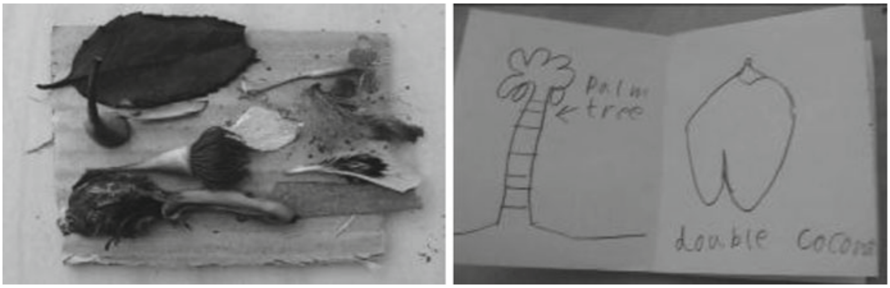


Fig. 19.1 Students' art products

from the ground in the garden and stick their collections onto a sticky card to make different pictures as they wish (see Fig. 19.1). In the activity named Sketching, Mark suggested that students do an observational drawing of the plant artifices displayed on their table. When Mark led the students into the Tropical Glasshouse, he recommended that they recorded what they found interesting in their books. The observational drawing and specimen collecting activities were designed to increase the students' interest in exploring the botanic garden and also developed their observation skills.

When Mark channelled students across the lawn, he suggested that they pick up a Eucalyptus leaf from the ground and crush it up to smell. Mark found that the students liked the smell, and he explained that the leaf is the favourite food of the Koala and the leaf can be used to flavour toothpaste and chewing gum. The students were also allowed to touch and smell the leaves when they were looking at the perfume plants. Most of the students identified mint and lemon from other plants according to their fragrant smell. By using their sense of smell, the students linked their daily life experiences to the botanic garden visit, which enhanced their direct experience of and knowledge about plants.

19.5 Discussion and Implications

Although Mark and Simon's teaching experiences and working contexts varied, there were some shared features in their observed lessons. First of all, Mark and Simon managed the visiting school groups in an effective way so that much of time was spent on learning rather than disciplinary issues. Moreover, both of them intended to control the conversations with students and dialogic interactions were rarely observed. Last but not least, they emphasized the direct experiences of the students and engaged them with hands-on activities such as pond dipping, observational drawings and plant collage. The findings of this study suggest that learning in botanic gardens is experience-oriented and the garden educators may benefit great from appropriate continuing professional development.

19.5.1 Learning in a Botanic Garden Is Experientially Based

Learning outside the classroom can provide students with an authentic experience of their real-life world (Ofsted 2008). School trips to botanic gardens can enable children to interact with the plants, gain first-hand information about different living environments, and increase their understandings of the natural world (Ballantyne and Packer 2002; Brody 2005). The findings from this study suggest how botanic garden educators support students' experience-based learning through adapting different teaching strategies. Kolb (1984) noted that 'the process whereby knowledge is created through the transformation of experience' (p. 41), thus knowledge is constructed through a combination of grasping and transforming that experience. Education in the botanic garden context might benefit from focusing on providing the students with concrete experiences and interactions with plants. Therefore, the educators have the responsibility to facilitate students to integrate their botanic garden experience with ongoing school subject knowledge. During and after observations of plants, educators might elicit students' thinking and assist them to conceptualise abstract concepts. The social constructivist theory of learning emphasises that knowledge is 'socially co-constructed as new ideas emerge from the blending of voices and gradually meshed to produce a dialogic outcome' (Chin 2007, p. 837). In this sense, the garden educators can ask a series of open-ended questions to prompt and guide students thinking and thus promote conceptual learning.

19.5.2 Supporting Botanic Garden Educators' Professional Development

Compared to their counterparts in schools, the botanic garden educators have to work with different students. There is a short time for them to assess students' prior knowledge and the academic level they are working at. Because the education programmes are designed based on the English National Curriculum, botanic garden educators have to update their knowledge about governmental documents and recent education research findings. As a result, botanic garden educators need support from their institutions to develop their professional knowledge and skills. The Botanic Garden Conservation International carried out an online survey recently and found that half the botanic gardens or ecological education sites responding required their education staff to have ongoing professional development. The findings of this study suggest that the botanic garden educators need to be given sufficient opportunities to further develop their subject knowledge and pedagogical skills constantly. The botanic gardens may establish a collaborative partnership with teacher training institutes to enable botanic garden educators to receive continuous professional development. In addition, frequent networking opportunities might facilitate these educators to share teaching experiences and thus to reflect on their own practices.

References

Allen, S. (2002). Looking for learning in visitor talk: A methodological exploration. In G. Leinhardt, K. Crowley, & K. Knutson (Eds.), *Learning conversations in museums* (pp. 259–303). Mahwah: Lawrence Erlbaum Associates.

Anderson, D., Lucas, K. B., & Ginns, I. S. (2003). Theoretical perspectives on learning in an informal setting. *Journal of Research in Science Teaching, 40*(2), 177–199.

Ballantyne, R., & Packer, J. (2002). Nature-based excursions: School students' perceptions of learning in natural environments. *International Research in Geographical and Environmental Education, 11*(3), 218–236.

Ballantyne, R., & Packer, J. (2009). Introducing a fifth pedagogy: Experience-based strategies for facilitating learning in natural environments. *Environmental Education Research, 15*(2), 243–262.

BGEN. (2009). Supporting inspirational learning about plants and their importance. Botanic Garden Education Network (BGEN). http://bgen.org.uk. Accessed 16 July 2009.

Bowker, R. (2002). Evaluating teaching and learning strategies at the Eden Project. *Evaluation and Research in Education, 16*(3), 123–136.

Bowker, R. (2004). Children's perceptions of plants following their visit to the Eden Project. *Research in Science and Technological Education, 22*(2), 227–243.

Brody, M. (2005). Learning in nature. *Environmental Education Research, 11*(5), 603–621.

Carson, R. (1998). *The sense of wonder*. New York: HarperCollins.

Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching, 44*(6), 815–843.

Cox-Petersen, A. M., Marsh, D. D., Kisiel, J., & Melber, L. M. (2003). Investigation of guided school tours, student learning, and science reform recommendations at a museum of natural history. *Journal of Research in Science Teaching, 40*(2), 200–218.

DfEE. (1999). *Science: Key stages 1–4: The National Curriculum for England*. London: Department for Education and Employment (DfEE).

DfEE. (2006). *Learning outside the classroom manifesto*. Nottingham: Department for Education and Skills (DfES) Publications.

Falk, J. H., & Dierking, L. D. (2000). *Learning from museums: Visitor experiences and the making of meaning*. Walnut Creek: AltaMira Press.

Glackin, M. (2007). Using urban green space to teach science. *School Science Review, 89*(327), 1–8.

Hein, G. E. (1998). *Learning in the museum*. New York: Routledge.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127.

Jones, V. (2000). *More than just plants: Engaging with the politics of identity at botanical gardens*. Paper presented at the Making sense of teaching and learning through environmental education research, Chelsea Physic Garden, London.

Kohn, D. (2008). Darwin the botanist. *Roots, 5*(2), 5–8.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs: Prentice-Hall.

Malone, K. (2008). *Every experience matters: Learning outside the classroom*. London: Farming and Countryside Education (FACE) and Department for Children, Schools and Families (DCSF).

Mortimer, E. F., & Scott, P. H. (2003). *Meaning making in secondary science classroom*. Maidenhead: Open University Press.

O'Donnell, L., Morris, M., & Wilson, R. (2006). *Education outside the classroom: An assessment of activity and practice in schools and local authorities*. London: Department for Education and Skills (DfES).

Ofsted. (2008). *Learning outside the classroom: How far should we go?* (No. NR-2008-30). London: Office for Standards in Education, Children's Services and Skills (Ofsted).

QCDA. (2008). *Science and the national curriculum aims*. Retrieved October 27, 2009, from http://curriculum.qcda.gov.uk

Rickinson, M., Dillon, J., Teamey, K., Morris, M., Choi, M. Y., Sanders, D., et al. (2004). *A review of research on outdoor learning*. London: National Foundation for Educational Research & King's College London.

Sanders, D. (2004). *Botanic gardens: 'Walled, stranded arks' or environments for learning?* Unpublished PhD thesis, University of Sussex, Brighton.

Sanders, D. (2007). Making public the private life of plants: The contribution of informal learning environments. *International Journal of Science Education, 29*(10), 1209–1228.

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(4), 605–631.

Slingsby, D. R. (2006). The future of school science lies outdoors. *Journal of Biological Education, 40*(2), 51–52.

South, M. (1999). *Can a botanic garden education visit increase children's environmental awareness?* Paper presented at the 4th International Congress on Education in Botanic Gardens, Kerala, India.

Stewart, K. M. (2003). *Learning in a botanic garden: The excursion experiences of school students and their teachers.* Unpublished PhD thesis, University of Sydney, Sydney, Australia.

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. London: Sage.

Tunnicliffe, S. D. (2001). Talking about plants: Comments of primary school groups looking at plant exhibits in a botanical garden. *Journal of Biological Education, 36*(1), 27–34.

Vygotsky, L. S. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Wellington, J., & Ireson, G. (2008). *Science learning, science teaching*. London: Routledge.

Wellington, J., & Osborne, J. (2001). *Language and literacy in science education*. Buckingham: Open University Press.

Westgate, D., & Hughes, M. (1997). Identifying 'quality' in classroom talk: An enduring research task. *Language and Education, 11*(2), 125–139.

Chapter 20
Knowledge Advancement in Environmental Science Through Knowledge Building

Jennifer Yeo and Yew-Jin Lee

20.1 Introduction

Inquiry has been the cornerstone of many science education reforms all around the world for the past five decades (Zion et al. 2007). Likewise in Singapore, the current primary science syllabus promotes inquiry as *the* overarching framework to achieve the aims of the science curriculum and to cultivate scientific literacy (MOE 2004, 2007). These aims include mastery of science content knowledge, development of skills and attitudes for science, and personal appreciation and decision making related to science and the environment. Inquiry has therefore been understood as the ideal vehicle for helping students to learn science content, master how to do science, and understand the nature of science.

Over the years, inquiry learning in science education has encompassed a wide spectrum of approaches—practical work, investigative work, discovery learning, problem solving, and project work as they closely resemble components of scientific work and activities by professional scientists. For example, practical work has been said to mimic the processes of observation, concentration, and reasoning needed to do science, whereas discovery learning is believed to capture the creativity of doing science. While inquiry activities in school may mirror some of the work of scientists, some researchers have questioned the ability of school science to nurture scientific thinking, at least in the form seen commonly among practicing scientists. Lee (2008), for example, has critiqued inquiry science in schools as being more visual spectacle and rule following than is often admitted, while Tan (2008) found

---

J. Yeo (✉) • Y.-J. Lee
Natural Sciences and Science Education, National Institute of Education, Singapore
e-mail: jennifer.yeo@nie.edu.sg

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_20,

that the completion of tasks was paramount as was the arrival at similar prescribed or canonical answers that the teacher had in mind. Such task-oriented activities that tend to dominate science classrooms everywhere (e.g., Hodson 1996; Hume and Coll 2008) often depart from the knowledge creation enterprise that characterizes the heart of scientific practice whereby novel findings or theories are produced and refined.

As an alternative to task-centered inquiry activities so prevalent in school settings, knowledge building (KB) is a pedagogical approach to inquiry that places student ideas at the center with the goal to work continually at the forefront of knowledge as learners advance the knowledge of their community (Scardamalia and Bereiter 2003). First adopted in elementary schools about 20 years ago for improving reading comprehension, KB has now spread to other subject areas including science. Such idea-centered activities more closely resemble the actual theory building and knowledge advancement practices of scientists compared to the emphasis on task completion and mastery of known knowledge during school science learning. In this study, our goal is to introduce KB as a powerful albeit underutilized pedagogical approach to learning environmental science among a group of school children in Singapore. Whereas some might wonder if such young children could achieve a high level of understanding of inquiry and of scientific knowledge in school settings, our study shows that adopting a KB approach managed to achieve many of these desirable learning outcomes. The research questions addressed in our study are (1) how do the students' ideas about environmental science progress while engaged in KB and (2) how does KB mediate students' advancement of ideas about environmental science? In the following sections, we describe KB for science learning and provide a case study that showed how a group of grade 5 students investigated the science of meat decomposition. This case example showed the students working continuously to advance the ideas of the group (community) that eventually resulted in a conceptual artifact—a generalized description of decomposition of meat, which underlies a sophisticated understanding of science. We conclude the chapter with some implications of how KB can be introduced to school science classrooms and the associated challenges with this pedagogy.

20.2 Knowledge Building as a Science Inquiry Approach

Knowledge building (KB) is defined as the "creative work with ideas that really matter to the people doing the work" (Bereiter and Scardamalia 2003, p. 68). Placing ideas at the center of its activity, KB involves creative knowledge workers seeking to advance the ideas of the community through collaborative efforts. Three key features about KB are highlighted below: idea improvement, creating conceptual artifacts, and collective effort and collaborative discourse. These characteristics distinguish KB in very subtle ways from allied forms of inquiry such as problem-based learning or project-based learning.

20.2.1 Idea Improvement

Idea centeredness is a key characteristic of KB. Traditional inquiry approaches in school such as practical work and investigative work often provide students a predetermined set of procedures to arrive at similar answers that will be tested at examinations. The focus of such cookbook-style inquiry is on completing the task as instructed rather than invoking critical thinking and arousing interest and curiosity to work creatively to advance/improve/learn ideas (Roth 1994). In a similar vein, contemporary inquiry activities such as design-based inquiry (e.g., building a drawbridge, tower, and rocket) and problem-based work (e.g., solving a science-based mystery) are often task-centered and may not lead naturally to inquiry into the underlying science even though there may be some aspects of knowledge creation such as creativity and critical thinking (Bereiter and Scardamalia 2003). Instead, the emphasis here is often placed on achieving a specific predetermined end state such as a correct solution, building a working model, or writing a report assessed for its alignment with canonical knowledge. Although allowing students greater ownership of the research problem and problem trajectory is something that we unanimously celebrate, such forms of learning remain uncommon even in explicitly inquiry-based learning.

In contrast to the aforementioned task-centered science inquiry approaches, KB places ideas in the center of its activity, not so much the actions that help achieve these tasks. Characteristic of the work of scientists and designers, there is no final state of perfection and no state of repose in the knowledge growth. Every idea is improvable, leading to better designs or refined scientific theories—there is little sense that one has "arrived." Placing ideas at the center of inquiry does not imply that investigations or research activities are not conducted or that one just "theorizes" in abstractions. KB tasks are not conducted as an end-in-itself, but, rather they are performed in order to advance ideas and by doing so, mirror the everyday activities of scientists, which as mentioned is never static. Through careful observations of phenomena, theories are invented to make sense of those observations. Changes in context or situations may, however, result in new observations. This may challenge prevailing theories which after further rigorous testing and investigation result in refined or new knowledge for the individual and the group (Lee and Roth 2007). In a similar vein, students doing KB might conduct investigations to find out the effect of size of seeds on the rate of germination of seeds, for example. However, such tasks are conducted to increase the understanding of a community of people (e.g., fellow learners, or people in a Listserv) who had developed an interest on the germination of seeds. This differs a great deal from the nature of school tasks, which seek a certain endpoint that is valued for school examinations. In other words, by placing ideas at the center of inquiry, idea improvement becomes an explicit principle that guides the efforts of students and teachers (Scardamalia and Bereiter 2006). The direct pursuit of idea improvement brings science learning closer in alignment with the genuine knowledge creation enterprise of scientific practices than the learning, if not memorization, of known facts in school science.

20.2.2 Creating Conceptual Artifacts

Creating artifacts is one key activity during school science inquiry. In practical work, a report that needs to conform to the style of the scientific method is often the eventual artifact expected. In project work or problem-based activities, common artifacts include a poster, a presentation, a model, or a worked solution. In contrast to these material artifacts, KB emphasizes conceptual artifacts such as theories, proofs, laws, and problem formulations. Such outcomes show greater affinity with those created by scientists: *theories* that can explain relatively huge sets of seemingly unrelated observations or *laws* that can account for every single instance of phenomenon in a simple and comprehensive manner (Elfin et al. 1999).

In KB, students are encouraged to work on self-selected problems with the goal of developing generalized knowledge. While such knowledge can be found in abundance in school science textbooks, they are nonetheless declarative knowledge *about* something; knowledge that is retrieved is often inert, that is, unable to be transferred to other contexts. In contrast, the conceptual knowledge referred to in KB is knowledge *of* a phenomenon, which includes not just declarative knowledge that can be easily regurgitated when asked but the implicit or intuitive knowledge that comes with deep understanding of the idea. Project- and problem-based activities may involve contextualized knowledge but often do not have generalized theory creation as its key focus. Rather, the artifacts created tend to be context specific, often leaving the task of learning generalized theories to learning during classroom lectures.

20.2.3 Collective Effort and Collaborative Discourse

Finally, KB emphasizes the community advancement of knowledge, which is radically different from the usual (traditional) educational practice which has individual achievement as the beginning and endpoint. KB seeks collective effort to advance the state of knowledge within the school classroom or interested group, rather than an individual inquirer. The goal of knowledge creation is not just for an individual's interest or glory but to produce ideas of value to others and the community. At this juncture, we cannot but find similarities here to the Wikipedia project that has just celebrated a decade of existence. In a science classroom, the community, which can be an entire class or a group of students, should share a common goal and direction in pursuing the advancement of the knowledge that it values. This calls for collective responsibility from every member in the community to contribute toward the advancement of community's knowledge rather than honoring an individual for what he/she knows (Scardamalia 2002).

With emphasis on collective effort to move the frontiers of the community's knowledge, collaboration becomes an important feature in KB. While group work may be a common feature in many inquiry activities, collaboration is less common in science classrooms (Yeo et al. 2008). Peer tutoring and cooperation are certainly common ways of organizing group work although such discourse patterns do not extend beyond sharing of information, providing opinions, simple agreement, or critiquing ideas. A robust KB discourse, on the other hand, seeks progress, common understanding, and expansion of ideas. Such discourse has been described as “constructive and progressive” (Bereiter et al. 1997) or “productive collaboration” (Barron and Darling-Hammond 2008). Given how different KB is from other inquiry-based learning approaches, we now support our claims by means of data taken from a larger study on teaching and learning using KB in Singapore.

20.3 A Case Example of Knowledge Building

This case example illustrates how an intact group of six primary five (equivalent of grade 5) boys from a local primary school performed KB as they went about finding out what happened during the rotting of meat. This was a self-forming group whereby students gathered according to their interests to pursue problems that had puzzled them or one which they found interesting. The school was a typical neighborhood school (catering to average ability students) in the western part of Singapore. One of its science teachers was a strong environment advocate who involved her students in environmental projects and activities organized by external agencies, including our research project. The latter aimed to introduce KB into primary schools in the context of environmental science. Known as the Nature Learning Camp, the program introduced KB to the school as an enrichment program conducted after curriculum hours. The participating students were selected based on their good academic results and keen interest in science. Two of them joined the program at primary four while the rest joined later in primary five at the start of the knowledge work on decomposition of meat. The group met once a week in the school’s computer laboratory during school term, except during examination period, school holidays, and other public holidays. During each session, the students would do a show-and-tell, conduct research, or participate in collaborative discussion through an online platform called Knowledge Forum. Figure 20.1 shows a screenshot of an online discussion on Knowledge Forum. Each note (i.e., ideas in a single posting) posted by the students is represented by a square. A title given by the author of the note and the author’s name appear beside the colored icon. Lines are used to link notes that are built on one another. A linear linkage of notes is referred to as a discussion thread (refer to Fig. 20.1).

Data on students’ knowledge-building process was captured on video and transcribed for face-to-face interaction. These data included show-and-tell sessions and small group face-to-face discussion. Online data was captured on the database of Knowledge Forum. These data were analyzed and examined for the field of talk (content) and the forms of interaction.

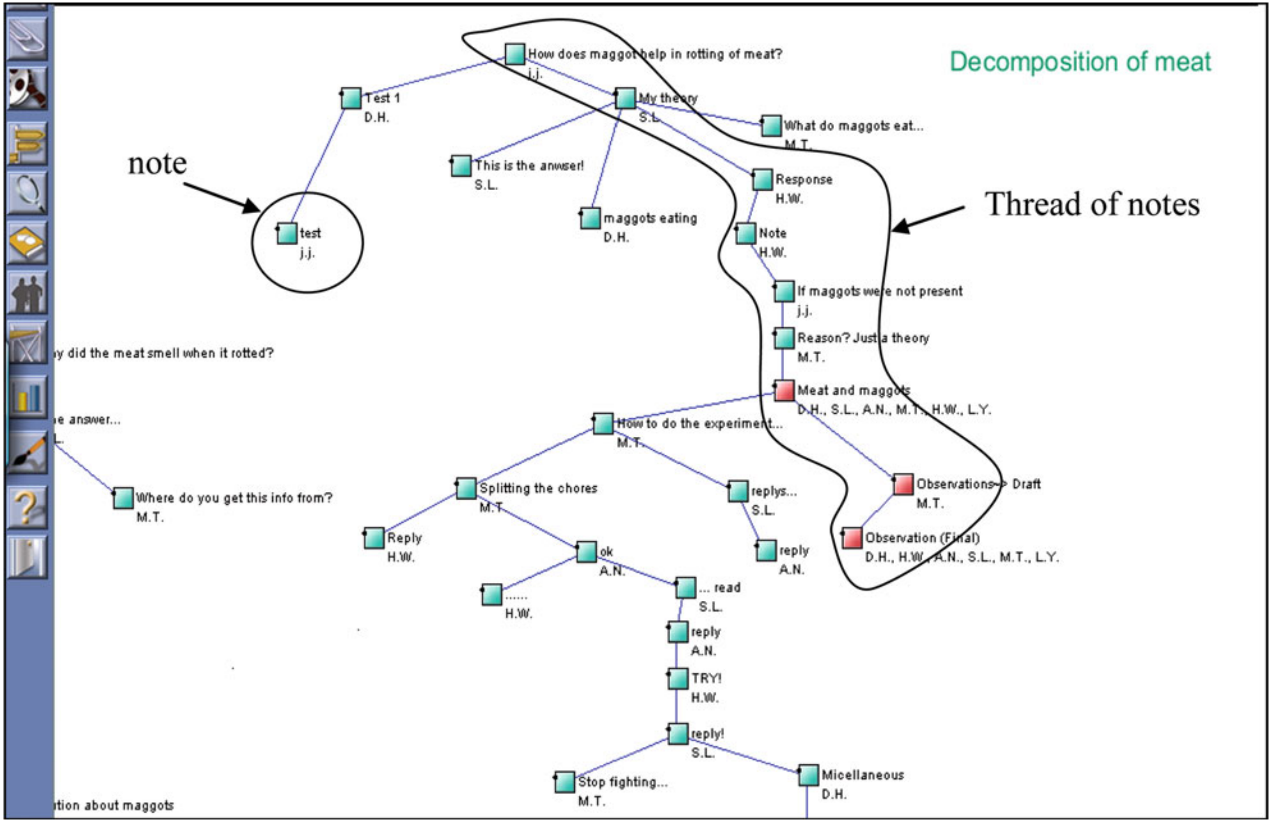


Fig. 20.1 Screenshot of online discussion on the online platform Knowledge Forum

20.3.1 What Happens When Meat Rots

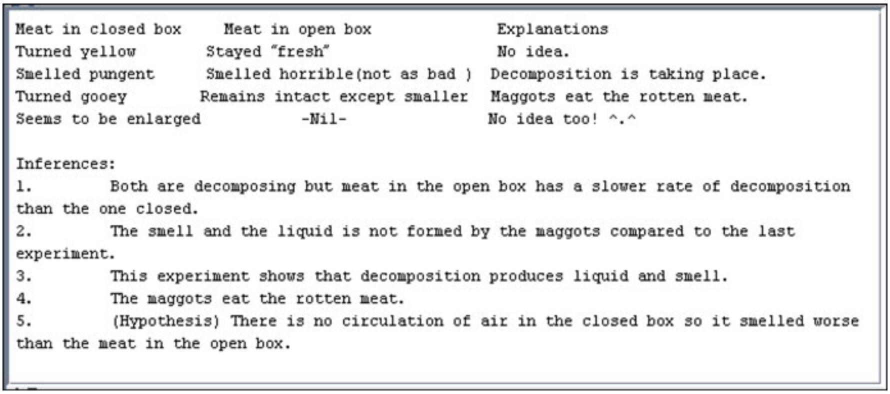
In this case example, the topic for KB in science was initially triggered by a discussion with this group of students about decomposition after a visit to their school garden. A boy wondered aloud what would happen when meat rotted, and this remark then generated much interest from the rest of the boys to find out more. The boys as a group were then left to conduct the science investigation on their own as the researchers monitored student progress on Knowledge Forum. The boys had some initial discussions on Knowledge Forum to decide how they would investigate their problem, what meat they would use, and who would bring the piece of meat home (they had two weeks before they had to report their findings). From their first show-and-tell two weeks later, it was understood that they bought a piece of chicken meat from their canteen vendor and persuaded one boy to bring the piece of meat home and monitor the process of rotting. This boy reported that the chicken meat was left to rot in the open initially but was wrapped up after a few days due to its stench.

What the children saw was more than what they had expected. An earlier note on Knowledge Forum showed that they had thought the meat would merely stink. Instead, they saw crawling maggots and yellow-colored meat that was somewhat mushy. Many questions were raised by the students, both during the show-and-tell as well as on Knowledge Forum, such as "what is the black thing" in the container, "what is the water from the meat," "why did meat smell when it rotted," and "how does maggot help in the rotting of meat." One of the questions that they raised was "what was the water," referring to the liquid they found in the box, which led to an exchange of "hypotheses" as shown in Excerpt 1.

Excerpt 1 "And what was the water?"

Speaker	Content
DL	And what was the water?
A	I don't know whether is it discharge from the maggots or something like that.
SZ	I think it's water vapour.
A	No. not water vapour.
SZ	I mean water than condensed. Water vapour that condensed. Water vapour can condense … Maybe it's the water vapour that condenses?

There were also quite a number of student notes posted on Knowledge Forum about the role of maggots in the process of decomposition. The first author challenged them to think of how the rotting of meat would be affected if there were no maggots on the meat. One of the boys suggested that bacteria would eat the meat and the meat would decompose. But they found that this theory could not explain whether rotting of meat would be affected if there were no maggots. They thus decided to test their ideas by conducting another investigation to resolve these differing/competing ideas. Their goals were, first, to further investigate what was the liquid in decomposition and, second, to compare whether a piece of meat with no maggots could rot faster than a piece of meat with maggots.



Meat in closed box	Meat in open box	Explanations
Turned yellow	Stayed "fresh"	No idea.
Smelled pungent	Smelled horrible(not as bad)	Decomposition is taking place.
Turned gooey	Remains intact except smaller	Maggots eat the rotten meat.
Seems to be enlarged	-Nil-	No idea too! ^.^

Inferences:

1. Both are decomposing but meat in the open box has a slower rate of decomposition than the one closed.
2. The smell and the liquid is not formed by the maggots compared to the last experiment.
3. This experiment shows that decomposition produces liquid and smell.
4. The maggots eat the rotten meat.
5. (Hypothesis) There is no circulation of air in the closed box so it smelled worse than the meat in the open box.

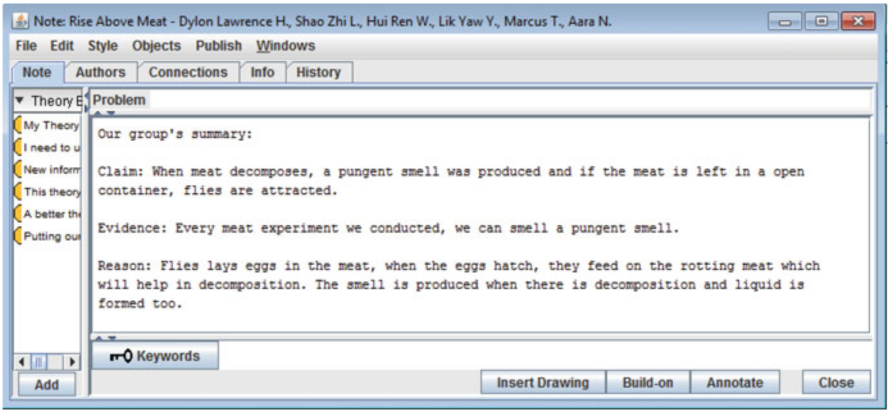
Fig. 20.2 Observation and inferences made from second investigation

After discussing on the online platform Knowledge Forum, they decided they had to set up a control to find out where the liquid came from by using two pieces of chicken meat, one left in the open and another covered to keep out the flies from laying eggs on the meat. The postings on Knowledge Forum also showed a negotiation among the students on their individual roles in this second investigation. Finally, the same boy agreed to do it one more time. They reported their findings two weeks later during show-and-tell as well as on the Knowledge Forum which is shown in Fig. 20.2.

Here, they found that both pieces of meat turned "gooey," with the closed container more gooey than the one in the open container. Therefore, they concluded that the liquid must be a product of decomposition.

Additionally, the new observations resulted in more puzzling problems to be raised. For example, they wondered why the two pieces of meat looked different, why flies were attracted to the meat in the open container, and so on. They thus decided to test out with different types of meat and in different conditions to generalize the process of decomposition of meat. This time, they investigated with dead lizards, fish and squid from the market, and dead stick insect. Finally, they summed up their findings with a group summary as shown in Fig. 20.3.

This summary showed students' generalization about the decomposition of meat in their claim that "when meat decomposes, a pungent smell was produced and if meat is left in an open container, flies are attracted." Extending their claims further, they also mentioned that maggots "feed on the rotting meat which will help in decomposition" and "smell is produced … and liquid is formed." While the students may not have arrived at very sophisticated theories or laws, their ideas progressed from simple, specific understanding of decomposition to more complex and generalized science-based descriptions of the process of decomposition, nonetheless.



Our group's summary:

Claim: When meat decomposes, a pungent smell was produced and if the meat is left in a open container, flies are attracted.

Evidence: Every meat experiment we conducted, we can smell a pungent smell.

Reason: Flies lays eggs in the meat, when the eggs hatch, they feed on the rotting meat which will help in decomposition. The smell is produced when there is decomposition and liquid is formed too.

Fig. 20.3 Group summary

20.4 Principles Mediating Knowledge Building

The above case example illustrates some principles of KB in an elementary science classroom, including idea improvement, conceptual artifacts, collective efforts, and collaborative discourse.

20.4.1 Idea Improvement

Knowledge attainment is the common factor in both school science and science enterprise. However, the similarity often ends there. While school science is often concerned with what people ought to know, science as enterprise is concerned with usefulness, adequacy, and improvability—what Bereiter and Scardamalia (2003) describes as belief mode and design mode, respectively. In this case example, the activities happening in the classroom were different from a usual science classroom activity. No knowledge about decomposition was taught explicitly beforehand nor were the experiments done to validate unquestionable knowledge presented, as often seen in classrooms operating in belief mode. Instead, the ideas are from different sources (e.g., students in Excerpt 1). These ideas, which formed the seeds of knowledge creation, were worked on and improved as a collaborative group. As one boy aptly put it during an interview, "the old idea is the foundation of all the other new ideas." What we saw in the case example was a group of boys treating an idea as an improvable artifact. They built upon their initial ideas about the liquid found in the box with the rotting meat and conducted investigations to test out their ideas. One boy mentioned in the interview that to "find out how the thing happens … we did the experiments, (because) we did not know what is the liquid." Through repeated investigations with different types of meat, they generalized the process of decomposition as they did in Fig. 20.3. From simple and specific knowledge about decomposition, the students' ideas progressed to a more complex and generalized description of the process. In this case, investigations were not conducted to validate a known piece of knowledge, but as a means to advance the group's ideas as students continually place ideas at the center of their activity. Students in this activity would be described by Bereiter and Scardamalia (2003) to be working in a design mode.

20.4.2 Conceptual Artifacts

The eventual artifact created by the boys in this case example is a generalized description of the process of decomposition of meat. Such generalized knowledge type is described by Bereiter and Scardamalia (2003) to be context general, as opposed to knowledge that is limited to specific context (e.g., engineering problems in PBL activities). However, this description is unlike the kind of declarative knowledge they could easily obtain from textbooks or other authoritative sources. While most elementary science textbooks would describe decomposition to be a process which results in the breaking down of the organic matter into simpler substances, these boys would have developed a much deeper understanding of this statement through this KB process. In their reflection notes, one boy wrote that "I have seen maggots for the first time in 10 years"; another summed up the process of decomposition in his own words, "flies are attracted to rotting meat, … liquid and a (horrid and pungent) smell is emitted …"; and a third wrote that he had now seen decomposition happening right in front of him. Extending to their daily life, one boy advised "never to leave fish/chicken/pork meat alone in the fridge unless you want a nightmare when you open it." Thus, these boys were not only able to verbalize the definition of decomposition in their reflection notes but also they could also visualize the process of decomposition since they had seen it happening right before their eyes and could relate the process to their everyday life. Such context-general knowledge, referred to as knowledge of a phenomenon by Bereiter and Scardamalia (2003), is definitely much richer than the mere declarative knowledge about decomposition found in school science textbooks. We argue that the creation of such context-general knowledge of phenomenon is made possible as students treated ideas as artifacts to be improved rather than mere completion of an activity.

20.4.3 Collective Effort and Collaborative Discourse

Collaboration is a process of shared meaning construction whereby its achievement is dependent on participants building on one another's ideas (Sawyer 2006). This calls for participants to be engaged in discourse that demonstrates commitment to progress, seeking common understanding, and expansion of knowledge base (Scardamalia and Bereiter 2006). This case example shows a group of five boys demonstrating collective responsibility toward knowledge building, albeit slowly but progressively as they went about the KB activity. We see instances of this responsibility emerging as they took up greater ownership in performing investigations and building on one another's ideas. Show-and-tell sessions also involved an increasing number of boys reporting what they found out from their investigation with more ideas generated. All these collective effort from each boy contributed toward the generalization of the process of decomposition.

Discourse patterns also changed as students assumed greater collective responsibility to advance the group's ideas. This can be seen in the discussion taking place on Knowledge Forum, which tended to be short in the earlier stages of knowledge building consisting of mainly question and answer. For example, questions such as "what happens when meat rots?" initiated by the teacher elicited single unbuilt answers such as "they will affect our health," "it can be decomposed by e.g. fungi," and "it decomposes, is smelly …." However, the discourse pattern changed as each student became more and more engaged in finding answers to the group's puzzling questions. For example, when planning an investigation to find out what happened when meat rotted, the discourse pattern was more argumentative. Excerpt 2 is an example of an argumentative discourse that shows students proposing (notes 4 and 7), challenging (turn 23), and supporting (turn 26) ideas on how they could go about investigating the process of decomposition. Here, we see students displaying a more critical stance toward ideas put forth.

Excerpt 2 What happens when meat rots?

Note	Author	Title	Content
1	DL, SZ, A, MT, HR, LY	Rotting of Meat	I need to understand what happens when meat rots?
4	MT	Steps to conducting our rotting meat experiment…	We need to get some meat and leave it in the open air on a plate to rot. Then, we should observe the characteristics of the rotting meat and note it down on a piece of paper. The End…
7	HR	Another reply	Good idea, maybe we should get several pieces of meat to observe on…..
23	DL	Several pieces of meat?	I need to understand why is there a need for several pieces of meat when you need only a piece of meat?
26	HR	Reason	Just in case something happens to one of them … but it's just in my opinion.

The argumentative discourse pattern was also observed when the students were discussing conceptual issues. Excerpt 3 shows the students collectively building their argument about the function of maggot in the rotting meat process among other things.

Excerpt 3 How does maggot help in the rotting of meat?

Note	Author	Title	Content
1	Teacher	How does maggot help in rotting of meat?	I need to understand how does maggot help in the rotting of meat?
2	SZ.	My Theory	I think the maggot just eats the rotten meat
4	HR	Response	Yeah, they eat anything organic.
5	HR	Note	Yeah, but they mainly eat meat … ROTTING meat….
8	Teacher	If maggots were not present	I need to understand if there are no maggots on the meat, how will the rotting of meat be affected?
9	MT	Reason?	My theory is that bacteria will eat the meat, and hence, decompose.
10	DL, SZ, A, MT, HR, LY	Meat and maggots	This theory cannot explain whether rotting of meat will be affected if there are no maggots. I need to understand whether a piece of meat with no maggots can rot faster than a piece of meat with maggots.
11	MT	How to do the experiment…	How to carry out the experiment on the next week of (so-called) school holidays- Step 1) A is going to take both containers of meat and keep it for the next week (he insisted on doing the experiment and HR has already kept it once). Step 2) A, you are going to write down your observations on both the containers and take some pictures too if you have time. Step 3) Bring the containers back like what HR did last time he brought back the rotting meat if it smells. Really. Step 4) Write down our observations by building on to 'Meat and maggots' Step 5) The end…
26	MT	Observations ~> Draft	Observations: Opened: 1) The box is infested with maggots, even on the outside. 2) Maggots were yellowish-brown in colour. 3) The meat was EXTREMELY dirty and smelly. 4) The meat looks normal (kinda fresh?), just that it stinks and looks like water has been sucked. 5) They are still alive in the container after 1 week. 6) When we opened the container, lots and lots of flies were coming and ate a very little portion of the meat.

<table>
<tr><td></td><td></td><td></td><td>Closed:
1) The meat turned yellow.
2) There were a lot of liquid, which was yellowish-brown and looks like slime.
3) Rotted.
4) No flies come to this container as it is, rotten.
5) No maggots were found on the inside (and the outside) of the container.
This is just a draft but informations are true.
~>The end<~</td></tr>
<tr><td>27</td><td>DL, SZ, A, MT, HR, LY</td><td>Observation (Final)</td><td><table>
<tr><td>*Meat in closed box*</td><td>*Meat in open box*</td><td>*Explanations*</td></tr>
<tr><td>Turned yellow</td><td>Stayed “fresh”</td><td>No idea.</td></tr>
<tr><td>Smelled pungent</td><td>Smelled horrible (not as bad)</td><td>Decomposition is taking place</td></tr>
<tr><td>Turned gooey</td><td>Remains intact except smaller</td><td>Maggots eat the rotten meat</td></tr>
<tr><td>Seems to be enlarged</td><td>-Nil-</td><td>No idea too!</td></tr>
</table>
Inferences:
1. Both are decomposing but meat in the open box has a slower rate of decomposition than the one closed.
2. The smell and the liquid is not formed by the maggots compared to the last experiment.
3. This experiment shows that decomposition produces liquid and smell.
4. The maggots eat the rotten meat.
5. (Hypothesis) There is no circulation of air in the closed box so it smelled worse than the meat in the open box.</td></tr>
</table>

Here, students were observed to be extending one another's ideas by hypothesizing (notes 2 and 9), elaborating (notes 4 and 5), challenging (note 10), and questioning (note 10) how maggots affect the rotting of meat as they built on one another's ideas. Such inductive, self-regulatory, and argumentative interactions are described by Dillenbourg (1999) to be characteristic of collaborative processes. Furthermore, the presence of the two group notes (notes 10 and 27) which represent the common knowledge and action of the group further supports the collaborative nature of work the students were engaged in. From what is shown in this case example, knowledge work discourse with its more constructive and progressive character could potentially advance students' scientific ideas.

20.5 Discussion and Implications for Science Learning

Idea improvement, creating conceptual artifacts, collective responsibility, community effort, and collaborative discourse are the key principles of KB. By analyzing students' talk online and off-line, we show how these principles could mediate creative knowledge work. The result is construction of new knowledge and development of valuable skills as students performed evidence-based investigation.

We have identified, through this case study, some enabling factors that lead to these successful outcomes. For one, problems that were authentic (i.e., of intrinsic interest) to the students, ideas that come from students' prior experience, observations from investigations, or even from authoritative sources contributed to the successful knowledge-building activity. This notion is long- and well-supported in the literature that draws on personal interest, motivation, and goal setting as the impetus for deep learning in science and indeed for all school subjects (Bransford et al. 1999; Hattie 2009; National Research Council 2006).

The findings from this study also suggest that tasks such as experiments should not be mere exercises or at least perceived to be by the students. Instead, teachers should allow students to take up collective responsibility to chart how they want to advance their ideas. However, such epistemic agency is only possible if teachers believe that their students are capable of creating knowledge that is useful to their community and in advancing the knowledge-building effort. Calling it "participating productively in science," the report by Michaels et al. (2008) paints an alternative vision of science that sees children as co-learners with teachers and as co-inquirers with scientists and peers.

What we see in this case example reported here does not happen overnight. Students had to get used to the idea that they were legitimate constructors, rather than receivers, of knowledge. They had to learn to engage in different types of discourse that was often different from the triadic discourse (Lemke 1990) found in science classrooms. Teachers also had to adjust to their new roles as co-constructors of knowledge and facilitators. They had to look beyond inquiry as mere vehicle to a set of predetermined knowledge. In this same spirit of knowledge building, science educators who wish to transform their science classroom practice need to recreate the concept of inquiry so that children are now legitimate participants of knowledge creation.

Knowledge building has shown advantages in improving the scientific literacy of students—core scientific knowledge and ability to conduct evidence-based investigations and participate in argumentation. By involving students directly in creative and sustained work, it is a promising inquiry model to enculturate students into the practices of science.

References

Barron, B., & Darling-Hammond, L. (2008). Teaching for meaningful learning. In L. Darling-Hammond, B. Barron, P. D. Pearson, A. H. Schoenfeld, A. H. Stage, E. K. Zimmerman, T. D. Cervetti, & Tilson, J. L. (Eds.), *Powerful learning: What we know about teaching for understanding* (pp. 11–70). San Francisco: Jossey Bass.

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In E. De Corte, L. Verschaffel, N. Entwistle, & J. van Merriënboer (Eds.), *Powerful learning environments: Unraveling basic components and dimensions* (EARLI advances in learning and instruction series, pp. 55–68). Oxford: Elsevier Science.

Bereiter, C., Scardamalia, M., Cassells, C., & Hewitt, J. (1997). Postmodernism, knowledge building and elementary science. *The Elementary School Journal, 97*, 324–340.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Dillenbourg, P. (1999). What do you mean by collaborative learning? In P. Dillenbourg (Ed.), *Collaborative-learning: Cognitive and computational approaches* (pp. 1–19). Oxford: Elsevier.

Elfin, J. T., Glennan, S., & Reisch, G. (1999). The nature of science: A perspective from the philosophy of science. *Journal of Research in Science Teaching, 36*, 107–116.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. London: Routledge.

Hodson, D. (1996). Laboratory work as scientific method: Three decades of confusion and distortion. *Journal of Curriculum Studies, 28*, 115–135.

Hume, A., & Coll, R. (2008). Student experiences of carrying out a practical science investigation under direction. *International Journal of Science Education, 30*, 1201–1228.

Lee, Y.-J. (2008). The trouble with inquiry science in schools: An ethnomethodological critique. In *The conference for Asian science education*. Kaoshiung: National Kaoshiung Normal University.

Lee, Y.-J., & Roth, W.-M. (2007). The individual collective dialectic in the learning organization. *The Learning Organization, 14*, 92–107.

Lemke, J. (1990). *Talking science*. London: Alex.

Michaels, S., Shouse, A. W., & Schweingruber, H. A. (2008). *Ready, Set, SCIENCE: Putting research to work in K-8 science classrooms*. Washington, DC: National Academy Press.

Ministry of Education. (2004). *Science syllabus. Lower secondary. Special/express/normal (Academic)*. Curriculum Planning & Development Division.

Ministry of Education. (2007). *Science syllabus. Lower secondary. Express/normal (Academic)*. Curriculum Planning & Development Division.

National Research Council. (2006). *America's lab report: Investigations in high school science*. Washington, DC: National Academy Press.

Roth, W.-M. (1994). Experimenting in a constructivist high-school physics laboratory. *Journal of Research in Science Teaching, 31*, 197–223.

Sawyer, R. K. (2006). Introduction: The new science of learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 1–18). New York: Cambridge University Press.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Chicago: Open Court.

Scardamalia, M., & Bereiter, C. (2003). Knowledge building. In J. W. Guthrie (Ed.), *Encyclopedia of education* (pp. 1370–1373). New York: Macmillan Reference.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 97–118). New York: Cambridge University Press.

Tan, A. L. (2008). Tensions in the biology laboratory: What are they? *International Journal of Science Education, 30*, 1661–1676.

Yeo, J., Lee, Y.-J., & Tan, S. C. (2008). How groups learn: Implications for collaborative work in science. In *The conference for Asian science education*. Kaoshiung: National Kaoshiung Normal University.

Zion, M., Cohen, S., & Amir, R. (2007). The spectrum of dynamic inquiry teaching practices. *Research in Science Education, 37*, 423–447.

Chapter 21
Issues and Challenges: Impacting Practice and Policy

Kim Chwee Daniel Tan and Mijung Kim

21.1 Impact of Science Education Research

In this book, science educators and researchers have addressed their responses and efforts to the challenges and issues of science education in the contexts of learning and teaching science, science teacher education, innovations and new technologies in science education, and science teaching in informal settings. However, for these responses and efforts to make a difference in school science, they need to influence the practices in classrooms and educational policy making. Unfortunately the impact of research on practice and policy seems to be still limited; teachers and policy makers have expressed scepticism about research evidence, indicating that there are large gaps in current research knowledge, that research is driven by the researchers' agendas rather than the users' needs (Baker et al. 2007; Bell et al. 2004; Millar et al. 2006; Nutley et al. 2002), that "there is a gulf between research design and real-world practice, and that research findings have limited applicability to their local contexts" (Nelson et al. 2009, p. 50).To make research findings and suggestions meaningful and connected to real world practice, there needs further reflection on these research-practice and policy issues.

K.C.D. Tan (✉)
Natural Sciences and Science Education, National Institute of Education,
Nanyang Technological University, Singapore
e-mail: daniel.tan@nie.edu.sg

M. Kim
Curriculum and Instruction, University of Victoria,
Victoria, BC, Canada
e-mail: mjkim@uvic.ca

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2_21,

21.2 Conceptual Change Perspectives on Research Impacting Practice and Policy

The classical perspective of conceptual change (Posner et al. 1982) could suggest *a* way to explain the lack of impact of research on practice and policy. It suggests that the intelligibility, plausibility, and fruitfulness of the research knowledge need to be considered in order to be of help to teachers and policy makers who are dissatisfied, in the first instance, with certain situations in the classroom or educational system. Assuming the teachers' and policy makers' experiences of conflict or dissatisfaction provide the impetus for them to explore the use of education research, education research needs to be first intelligible to them; the discourse used by researchers may be different from the teachers and policy makers, and they also may not have the requisite knowledge and background to read and interpret the research material; few researchers would write with the teacher or policy maker in mind (Bell et al. 2004; Nelson et al. 2009; Taber 2001).

Educational research also needs to be available to the users in terms of awareness that relevant research exists and access to such research. Teachers and policy makers are generally unaware of relevant research available (Liu 2001; Taber 2001) and they may have to spend much time ploughing through the large volume of material in databases and/or results generated by search engines, decreasing their motivation to use research material. If they know of relevant research, they may have difficulty acquiring the material because of the cost of buying the research publications or paying the membership subscription to get access to the journals or databases.

Often the lack of implementation details may put the teachers and policy makers off using research as they are uncertain of the plausibility of the research; they need to look at lesson plans, resources and assessment used, and know what the teachers and students actually did in the studies to make judgement calls (Ratcliffe et al. 2006). In addition, though they may believe in the findings of a study, they may think that the research has limited applicability because the research context may be different from their local contexts or they may have difficulty adapting and implementing the findings (Millar and Hames 2006; Nelson et al. 2009). Nutley et al. (2002) and Baker et al. (2007) agree that successful interventions or programmes are highly dependent on context, for example, time, students, teachers, school environment and leadership, examination requirements and availability of resources. Interestingly enough, Nelson et al. (2009) reported that their study participants also wanted to know what did not work in the studies so that they would be able to avoid the pitfalls that the researchers encountered; however, things that do not work are seldom mentioned in research publications. Teachers and policy makers often complain that research is not timely enough in that the findings may be outdated, and hence of not much use, by the time the research is completed as the initiatives of the past may be superceded by newer educational initiatives in their contexts (Nelson et al. 2009). These issues often lead to the lack of plausibility and fruitfulness of research to teachers and policy makers.

21.3 Concluding Remarks

In addition to doing research in science education to determine how best to increase the science literacy of students and help them thrive in the twenty-first century, there is also an urgent need to ensure that practice in the classroom and policy making take into account the research undertaken. The large quantity of research available and time required to sieve through them, the timeliness of the research, the format in which the studies have been reported and the language used in these reports, and the lack of access to the published studies make them virtually inaccessible to practitioners and policy makers (Nelson et al. 2009; Wandersee et al. 1994). Thus, researchers need to understand the needs and constraints of teachers and policy makers in order to help align their research to these needs and constraints (Nelson et al. 2009). Systems need to be developed for researchers to enhance the relevance and transformation of research findings to practitioners. For example, researchers and/or relevant intermediaries need to work with teachers and policy makers to "aggregate, translate, and apply research evidence directly to specific, highly local issues" (Nelson et al. 2009, p. 52), and "findings need to be interpreted into implications that apply to specific problems and decisions" (Tseng 2010, p. 16). This can be accomplished by building a community of practice to establish collaborative and mutual reflection on research agendas and needs of teachers and policy makers, sharing and understanding conflicts, introducing relevant research, supporting access to research findings and resources, and interpreting research in their own contexts, times, and places. Within this collaborative reflection, our language, knowledge, meaning making, and problem solving will be renegotiated and transformed to build up the applicability of research in practice and the enquiry of practice in research agendas. To make communication active and fruitful in the community of practice, there also needs to be systemic support, shared interests, and respect and openness among members, which opens up another realm of research for us. If little is done in this direction, the complaints that "educational research has been rather more preoccupied with arcane theoretical debates (or the professional ambitions of academics) than making a difference in the classroom or decision-making forums" (Baker et al. 2007, p. 794) will persist and science educational research will merely become an end to itself, serving only the researchers' career interests, instead of a means to an end, to improve the teaching and learning of science in the classroom.

References

Baker, E. L., Baker, R., Berger, J. G., Darmon, A., Gogolin, I., Hogan, D., Niemi, H., & Wolter, S. (2007). Improving educational research: TLRP's projects and themes. *British Educational Research Journal, 33*(5), 781–804.

Bell, M., Cordingley, P., Evans, D., Holdich, K., & Saunders, L. (2004). *What do teachers want from research and does the research address those needs*? Paper presented at the Annual British

Educational Research Association Annual Conference, University of Manchester. Retrieved from http://www.leeds.ac.uk/educol/documents/00003866.htm

Liu, X. (2001). Synthesizing research on student conceptions in science. *International Journal of Science Education, 23*(1), 55–81.

Millar, R., & Hames, V. (2006). Using designed teaching materials to stimulate changes in practice. In R. Millar, J. Leach, J. Osborne, & M. Ratcliffe (Eds.), *Improving subject teaching: Lessons from research in science education* (pp. 100–116). London: Routledge.

Millar, R., Leach, J., Osborne, J., & Ratcliffe, M. (2006). Research and practice in education. In R. Millar, J. Leach, J. Osborne, & M. Ratcliffe (Eds.), *Improving subject teaching: Lessons from research in science education* (pp. 3–23). London: Routledge.

Nelson, S. R., Leffler, J. C., & Hansen, B. A. (2009). *Toward a research agenda for understanding and improving the use of research evidence*. Portland: Northwest Regional Educational Laboratory.

Nutley, S., Davies, H., & Walter, I. (2002). *Evidence based policy and practice: Cross sector lessons from the UK.* Research Unit for Research Utilisation, University of St Andrews. Retrieved from http://www.kcl.ac.uk/content/1/c6/03/46/00/wp9b.pdf

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211–227.

Ratcliffe, M., Bartholomew, H., Hames, V., Hind, A., Leach, J., Millar, R., & Osborne, J. (2006). From evidence to impact: Users' perception of research and its influence on their practices. In R. Millar, J. Leach, J. Osborne, & M. Ratcliffe (Eds.), *Improving subject teaching: Lessons from research in science education* (pp. 134–151). London: Routledge.

Taber, K. S. (2001). Constructing chemical concepts in the classroom?: Using research to inform practice. *Chemical Education Research and Practice in Europe, 2*(1), 43–51.

Tseng, V. (2010). *Learning about the use of research to inform evidence-based policy and practice: Early lessons and future directions*. William T. Grant foundation 2009 annual report. New York: William T. Grant Foundation.

Wandersee, J. H., Mintzes, J. J., & Novak, J. D. (1994). Research on alternative conceptions in science. In D. L. Gabel (Ed.), *Handbook of research on science teaching and learning* (pp. 177–210). New York: Macmillan.

About the Authors

Ossi Autio is a Senior Lecturer in technology education at the University of Helsinki. In 1982 he began working in primary schools, upper secondary schools and vocational schools as a teacher of technology education. He has been teaching technology education at the University of Helsinki since 1989. His main research interests are students´ technical abilities and practical solutions for creative problem solving in technology education.

Elaine Blake is a doctoral student at Curtin University, Western Australia. Her thesis investigates science opportunities for children under 5 years of age in early learning centres. Elaine is an Early Childhood Consultant for the Association of Independent Schools, Western Australia, and is ultimately aiming to improve emergent science and literacy skills for young children. Her experience as an educator includes 22 years teaching in both early childhood education and tertiary education, plus 5 years as Head of an Independent Junior School. Elaine studied Reggio Emilia philosophy in Italy, was awarded a national science fellowship to study interactive science for young children in Australia and Europe and is past Western Australia president of two national professional associations: The Australian College of Educators, and Association of Literacy Educators Australia. Elaine is co-editor of the science resource *Planting the Seeds of Science*, product of a 2-year nationally funded project to develop science resources for early childhood teachers.

Dr. Martina Calais is a Senior Lecturer at the School of Engineering and Energy at Murdoch University in Western Australia, Australia. At Murdoch, Martina coordinated the development of Australia's first Renewable Energy Engineering Degree and she now teaches in the Renewable Energy and Electrical Power Engineering area. She is closely associated with Murdoch University's testing laboratory of photovoltaic system components and is actively involved in research on solar (photovoltaic) system technology. Martina has a keen interest in renewable energy education including developing renewable energy engineering training facilities.

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2,

Dr. Yvonne Carnellor is the Coordinator for the Bachelor of Education (Early Childhood Education) program at Curtin University in Western Australia, Australia. She has an international reputation in early childhood teaching and learning, curriculum and research, and has worked in partnerships with schools and school systems across Australia and New Zealand on a wide range of early childhood oriented teacher professional development programs. Yvonne's early childhood education expertise includes: mathematics and science learning, gifted and talented education, learning difficulties and young children's social and emotional development.

Yam San Chee is an Associate Professor in the Learning Sciences and Technologies Academic Group and the Learning Sciences Lab at the National Institute of Education, Nanyang Technological University, Singapore. He obtained his B.Sc. (Econ) with Honours from the London School of Economics and Political Science, University of London, and his Ph.D. from the University of Queensland, Australia. Chee's research focuses on new literacies and new media in education, with a special emphasis on game-based learning. Recent games developed for research include Space Station Leonis and Escape from Centauri 7. Current games developed through National Research Foundation funding are Legends of Alkhimia and Statecraft X. He was the founding Executive Editor of *Research and Practice in Technology Enhanced Learning*, the journal of the Asia-Pacific Society for Computers in Education. He is currently an Associate Editor of the *International Journal of Gaming and Computer-Mediated Simulations* and an Advisory Board Member of *Journal of Educational Technology and Society*.

Shien Chue obtained her Ph.D. from the National Institute of Education, Singapore. Her thesis focused on the multimodal use of non-verbal meaning-making resources in the teaching and learning of organic chemistry. Having also a keen interest in curriculum implementation and evaluation, she was involved in a research project on fidelity of implementation of science curriculum reforms in local secondary schools. Other research interests include multimodality of scientific communication and gestures in scientific discourse

Dr. Barbara A. Crawford is a tenured full Professor of Science Education at The University of Georgia in Athens, GA, USA. She received her Ph.D. in Science Education from The University of Michigan and earned degrees in microbiology and biology. She recently was elected a Fellow of the American Association for the Advancement of Science (AAAS). Her research focuses on inquiry-based pedagogy and nature of science, teacher knowledge and beliefs, science teacher education, and support of diverse children in learning what science is. She served on the Editorial Board and as reviewer for the *Journal of Research in Science Teaching*, *Science Education*, the *Journal of Science Teacher Education*, and *International Journal of Science Education*, and as elected member of the Board of Directors for the National Association of Research in Science Teaching (NARST) and the Association of Science Teacher Education (ASTE). Her articles are published in the *International Journal of Science Education*, *Journal of Research in Science Teaching*, *Science Education*, *Journal of Science Teacher Education*, *Research in Science Education*, among others.

Julie Crough's interest in connecting and aligning science education in schools with real world science evolved during her years working for the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Living and working in remote locations in Australia she also realised the challenges teachers and students faced accessing reliable resources. While remote areas are often associated with social disadvantage, they are culturally and environmentally rich, thus providing unique opportunities for relevant science education. For nearly a decade Julie has been actively integrating these factors with educational technologies, to help improve learning outcomes. Through the Tropical Savannas Management Cooperative Research Centre and Charles Darwin University, Julie has collaborated with researchers, school teachers and students to design, develop and implement accessible online resources (namely, EnviroNorth—http://www.environorth.org.au). Julie is currently undertaking a Professional Doctorate in Tropical Environmental Management. She has a Masters degree in Science Education and an Honours degree in Science.

Reinders H. Duit is Professor Emeritus of physics education at the Leibniz-Institute for Science and Mathematics Education (IPN) in Kiel, the national institute for science education research in Germany. His research interests include the role of students' and teachers' conceptions in teaching and learning science with a particular emphasis on the role of analogies and metaphors, teaching and learning processes from conceptual change perspectives, quality development in schools and educational systems, teacher professional development and video-based studies on the practice of science instruction. He is also a co-developer of the Model of Educational Reconstruction that intends to support efficient instructional design. In 2008 he received the inaugural Honorary Medal for his contributions to science education research in Germany from the Association for Chemistry and Physics Education (GDCP) and in 2010 the Distinguished Contribution to Science Education through Research Award from the National Association of Research in Science Teaching (NARST).

Louise Fogg has 25 years' teaching experience in the Northern Territory (NT) and has worked as a project manager in the NT Department of Employment and Training for the last 6 years, focusing on curriculum, pedagogy and assessment at a system, school and classroom level. She has completed a Masters in Education with an information technology focus and her interest lies in the design of online inquiry-based learning environments. Louise has recently worked on the national Science by Doing project developing digital curriculum resources and professional learning modules, as well as a professional learning approach for secondary science teachers. Louise is also a trained Cognitive Coach SM. She is currently working as a principal in a small remote NT school, supporting teachers to inquire into the impact of teaching on the achievement of their students and developing a strong collaborative work culture.

Dr. Sandra Frid is an Associate Professor in the School of Education at Curtin University in Western Australia, Australia. Her background and expertise span early childhood through to tertiary teaching and learning, curriculum development and research. Sandra's research focuses on enhancing the professional capacities of pre-service and in-service teachers, particularly in relation to mathematics. She is actively involved in developing and delivering innovative learner-centred teaching practices in mathematics. Sandra also has a special interest in supporting rural and regional teachers.

Dr. Christine Howitt is an Associate Professor in early childhood and primary science education at the Graduate School of Education at the University of Western Australia, Australia. She has an interest in early childhood and primary science teaching and learning, curriculum development and research. Christine's research focuses on young children's science learning in both formal and informal contexts, more recently with an emphasis on the science teaching and learning opportunities provided within early learning centres. This includes ethical and methodological issues associated with using very young children in research. She is also actively involved in research with pre-service and in-service teachers that ultimately increases the amount of science taught in the early childhood and primary classroom. Christine is co-editor of the science resource Planting the Seeds of Science, the product of a 2-year nationally funded project to develop science resources for early childhood teachers.

Mingfong Jan is currently a Research Fellow at the Learning Sciences Lab, Nanyang Technological University, Singapore. He was awarded his Ph.D. degree from the Educational Communications and Technology (ECT) division of Curriculum and Instruction at the University of Wisconsin-Madison in 2009. He is interested in how new media, especially social and interactive media, may be designed to foster a participatory culture of learning. Between 2004 and 2009, he was deeply involved in three research projects funded by the U.S. Department of Education, MacArthur Foundation and University of Wisconsin Systems to investigate the educational affordances of mobile media, such as GPS-enabled Handheld Augmented Reality Games. In a joint project between Harvard, MIT and UW-Madison, he takes the lead to design a 10-day role-playing learning program for argumentation. In Singapore, he continues his research in investigating how digital media can be designed to help students think more deeply about learning and themselves.

Syh-Jong Jang is Professor at the Graduate School of Education and Center for Teacher Education, Chung Yuan Christian University in Taiwan. He received his Ph.D. in Science Education from the University of Texas at Austin. His research expertise is PCK and TPCK. He has published a lot research papers which focus on technology in teacher education and innovative science teaching in all levels. He grants many research projects from NSC. He served in the following professional positions: Director of Professional Development Center, Chung-Yuan Christian University, Commissioner of the Taiwan Institute of Education to review the instructional materials for elementary and junior high school science textbooks, FT PGDE(P) Program External Examiner—The Hong Kong Institute of Education. He is the Editor for the journal *PCK in Science and Mathematics* and reviews papers for *Computers and Education*, *Teaching and teacher Education*, *International Journal of Science Education*, *Journal of Computer Assisted Learning*, *AERA*, and *JRST*.

Yong Jae Joung is an Assistant Professor of Gongju National University of Education, Korea. He received his Ph.D. in Science Education from the Seoul National University, and was a postdoctoral research fellow, 2006–2007, at Monash University. His research interests include the nature of science and scientific methods in science education, conceptual learning of science with philosophical views and the relationship between individuals and community in science learning.

Mijung Kim is an Assistant Professor at the Department of Curriculum and Instruction at the University of Victoria. She worked at National Institute of Education, Singapore before she moved to the current institution. Her research interests include scientific literacy, STSE, inquiry-based teaching and environmental education. Her current research focus is on students' reasoning and argumentation in the context of socioscientific and environmental issues.

Jari Lavonen is a Professor of physics and chemistry at the University of Helsinki. In 1985 he began working in primary school and upper secondary school. After that he served about 10 years in a teacher training college as a Senior Lecturer at the department of teacher training in the field of science and technology before he was appointed Professor of physics and chemistry in 2005. His main research interests are creative problem solving in education and using information and communication technology in science and technology education.

Yew-Jin Lee is an Associate Professor in science education; his research focuses on sociocultural aspects of human learning and he studies curriculum implementation, knowledge-building and informal science education. With W.-M. Roth and L. Boyer, he has published 'The Eternal Return: Reproduction and Change in Complex Activity Systems' and edited a volume on science education in Asia.

Dr. Simon Lewis is an Associate Professor in the Department of Chemistry at Curtin University in Western Australia, Australia. He leads the Forensic and Analytical Chemistry Research Group. His research is focused on chemical techniques applied to forensic analysis, focusing in particular on fingerprint detection, decomposition chemistry and the crime scene. Simon is enthusiastically involved in outreach programs, using forensic science and analytical chemistry as vehicles to engage children of all ages in science.

Dr. David Lloyd is a Lecturer in Science and Mathematics Education in the undergraduate award, Bachelor of Education (Primary and Middle), and teaches in, and coordinated, the general study, Local and Global Environments, which provides undergraduate courses in science and sustainability studies. He has been a Chief Investigator in the ARC project—Redesigning Pedagogies in the North (RPiN) and the Australian Government's Diversity and Structural Adjustment Fund (DASA) Aspirations Project to improve outreach programs to schools. His own research has been in the use of integral futures studies in science learning as well as transdisciplinary approaches to the teaching and learning in science, mathematics and society and environment education. He is a member of the Hawke Research Institute for Sustainable Societies and the Barbara Hardy Centre for Sustainable Urban Environments. Before joining the University David taught in secondary and area schools as a chemistry, science and mathematics teacher and has been a senior master in science education and a middle school coordinator.

Dr. Mauro Mocerino is an Associate Professor and Director of Undergraduate Studies in the Department of Chemistry at Curtin University in Western Australia, Australia. His chemistry research involves the design, synthesis and study of molecules for specific applications, including control of crystal growth and treatment of diabetes. His education research focuses on improving the understanding of how students learn chemistry and what can be done to improve their learning.

Karen Murcia (Ph.D.) is an Associate Professor at Edith Cowan University, Perth, Western Australia. She is the convener of the School of Education's Science and Mathematics Learning and Research Cluster and the Primary Education program coordinator. Dr. Murcia's expertise and research is focused on learning and teaching for scientific literacy and digital interactive pedagogies. She has worked extensively in school based research partnerships, using action research principles to support teachers as classroom based researchers who engage with the process of designing, implementing and evaluating new strategies for improving teaching and students' learning outcomes. Dr. Murcia is an executive board member of the Edith Cowan University, Centre for Schooling and Learning Technologies (CSaLT) and a member of the journal review boards for *Research in Science Education*, the *Journal of the Australian Association of Science Education Research Teaching Science*, the *Journal of the Australian Association of Science Teachers*, and *Issues in Educational Research* and the *Journal of the Australian Association of Educational Researchers*.

Helena Näs taught biology, chemistry and mathematics for 10 years in secondary and upper secondary schools, before becoming a lecturer at the Department of Science and Mathematics Education, Umeå University. After 9 years as a lecturer at Umeå University she defended the thesis 'Teaching Photosynthesis in a Compulsory School Context—Students Reasoning, Understanding and Interactions'. She is currently senior lecturer at Umeå University with 50% research and 50% teaching. Her research interest is the teaching of science at the junior level of the compulsory school context. Her research focuses teachers' understanding of science and their professional growth.

Dr. Kathryn Paige is a senior lecturer in science and mathematics education at the University of South Australia. Having taught for 17 years in a primary classroom, her doctoral studies investigated primary teachers' beliefs and practices in thinking and working scientifically and technologically. Her research interests include preservice science and mathematics education in the primary/middle years, transdisciplinary teaching and learning, education for sustainability (EfS) and place based education. Current projects include Citizen science: connecting students to the natural world, and the urban ecology strand of the Aspirations Project to improve school retention and achievement. Past projects include Redesigning Pedagogies in the North, and the Distance Education Project in the Eastern Cape, South Africa.

Emeritus Professor Lesley Parker was Senior Deputy Vice Chancellor (1997–2004) of Curtin University in Western Australia, Australia. In 2005 she was appointed Planning Director of the then Carrick Institute of Learning and Teaching in Higher Education. She joined the Science and Mathematics Education Centre at Curtin in 1991 and continues to work with colleagues focusing on reform in science, mathematics and engineering education. Lesley was Foundation Chair of the Board of Directors of education.au limited (1997–2008) and was a member of Council of the National Science and Technology Centre (1997–2003). She has more than 30 years' experience in leadership, research, teaching and policy in all sectors of education at the national and international level.

Professor Susan Rodrigues conducts research into the teaching and learning of science. She is a Professor in Science Education at the Northumbria University. Prior to that she was a Professor at the University of Dundee; the Director of the Institute for Science Education in Scotland, located at the University of Edinburgh; the Director of Initial Teacher Education at Stirling University; a Senior Lecturer at the University of Melbourne, a Senior Research Officer at the National Foundation for Educational Research; and a Lecturer at the University of Durham. She started her career as a teacher of science and physical education. Her research explores issues such as the language of science and how ICT can be used to transform teaching and learning in science.

Dr. Len Sparrow is an Associate Professor in the School of Education at Curtin in Western Australia, Australia. Within the School he has had various leadership roles including that of Deputy Head. Len is a leader in mathematics teacher education, earning numerous Australian teaching awards. His current research centres on teacher professional development in science, mathematics and ICT. Len also has a special interest in supporting rural and regional teachers.

Niwat Srisawasdi undertook his degrees in Bachelor of Secondary Education, majoring in Physics and Mathematics, and a Master of Science Education from Khon Kaen University, Thailand. He then went on to Mahidol University, Thailand, to earn his Ph.D. in Science and Technology Education in 2009. During his Ph.D., he went to the University of Northern Colorado for a year. After his Ph.D., he joined Khon Kaen University as a lecturer in Department of Science Education, Faculty of Education. He is a member of the editorial review board for the Science Education Review. His research area is physics education and nanoscience education. His research interests are the optimization of computer-based learning environments and the applications of advanced technologies for the teaching and learning of science.

Ek Ming Tan is a trained schoolteacher on secondment to the Learning Sciences Lab, National Institute of Education, Singapore, as a lecturer (research). He obtained his B. Arts from the National University of Singapore and a Masters in Education from the University of Western Australia. Prior to his current position, he was a level head in a Singapore Secondary School and acting head of Department for English Language and Literature.

Kim Chwee Daniel Tan started his career as a chemistry teacher in 1990. He has been a faculty member of the National Institute of Education since 1998. He held a concurrent appointment in 2006–2007 as an Assistant Director in the Educational Technology Division, Ministry of Education. He is currently Associate Professor and Deputy Head (Teaching and Curriculum Matters) in the NSSE AG. He teaches higher degree courses as well as chemistry pedagogy courses in the pre-service teacher education programmes. His research interests are: chemistry curriculum, translational research, ICT in science education, students' understanding and alternative conceptions of science, multimodality and practical work.

David F. Treagust is Professor of science education at Curtin University in Perth, Western Australia, where he teaches campus-based and international courses on teaching and learning science. His research interests are related to understanding students' ideas about science concepts, and how these ideas can be used to enhance the design of curricula and improve teachers' classroom practice. A particular emphasis is given to the role of multiple representations in learning science and the further development of conceptual change oriented instructional approaches. He is past president of the National Association of Research in Science Teaching (NARST) and a recipient of the Association's 2006 Distinguished Contributions to Science Education through Research Award.

Professor Jo Ward is the Dean of Science and Computing at Curtin University in Western Australia, Australia. She has a strong commitment to teaching and learning in mathematics and science. Jo has played a major role in the design, monitoring and renewal of mathematical and science units, in particular taking account of the impact of new technology and making them more suitable for external/distance education students. Jo has also been instrumental in addressing the generic skills development of tertiary students. She is extensively involved in policy development in relation to teaching and learning, leading to major restructuring of science degrees at Curtin. Jo is also a champion of science and mathematics outreach into all levels of schools.

Jenni Webber currently teaches at Nhulunbuy Primary School in remote North East Arnhemland of the Northern Territory, Australia. Living in the Top End of Australia for more than 20 years, she has a passion for engaging students with their local environment. Prior to teaching, Jenni worked in zoos, museums and science centres across Australia and draws on these experiences and expert knowledge to engage her students. In particular, Jenni strives to integrate local Indigenous Knowledge and Western Science to help students better understand our world. She has a Bachelor of Science and a Master of Education, is an executive member of the Science Teachers Association of the Northern Territory, and Australian Science

Teachers Association Federal Council Member. She has been actively involved in the development of the Australian Curriculum in Geography and Science. Jenni hopes to continue to engage students and educators to teach and learn about their local environments.

Jennifer Yeo is an Assistant Professor in science education in National Institute of Education, Singapore. Her research interests are in the areas of knowledge-building, computer-supported collaborative learning and science meaning-making in elementary and high school settings.

Hye-Gyoung Yoon is a Professor of Chuncheon National University of Education, South Korea. Her research interests include science teacher education: dilemmas or difficulties teachers/pre-service teachers experience, effective/integrated way of enhancing teachers' practical knowledge and teaching skills.

Larry D. Yore is a University Distinguished Professor, Emeritus, in the Faculty of Education at the University of Victoria, Victoria, British Columbia, Canada. In 47 years of teaching and researching at elementary, secondary and tertiary levels, he has been engaged in developing provincial science curricula, national science frameworks, national K-12 assessment projects and several federally funded teacher enhancement, reform and research and development projects in Canada and the USA. He has served on or is currently a member of the editorial boards/panels of the *Journal of Research in Science Teaching*, *School Science and Mathematics, Science Education*, *Journal of Science Teacher Education*, *Journal of Elementary Science Education, International Journal of Science Education*, *L1—Educational Studies in Language and Literacy, Science and Technology Education*, and *International Journal of Science and Mathematics Education*. His recent research focuses on the constructive, communicative and persuasive roles of language in doing and learning science. He has published numerous journal articles, edited books and chapters; coauthored elementary science textbooks; edited special issues related to aboriginal knowledge about nature and naturally occurring events, applications of language arts in science education, PISA results and mathematical and scientific literacies; and presented numerous lectures and workshops. In 2012, he was honoured with the NARST Distinguished Contributions though Research Award for his achievement in and contribution to science education.

Benny Hin Wai Yung is Associate Professor in the Faculty of Education, the University of Hong Kong. He was Head of Division of Science, Mathematics and Computing. His main research areas are teacher professional development, pedagogical content knowledge and school-based assessment.

Dr. Marjan Zadnik is an Associate Professor in the Department of Applied Physics at Curtin University in Western Australia, Australia. He was the inaugural Dean of Teaching and Learning in Science and Engineering at Curtin. Marjan has worked for many years on improving students' learning and colleagues' teaching of physics and astronomy through research and the application of innovative ideas. He is passionate about effective and engaging teaching and learning of science concepts, and sharing that passion with tertiary students.

Junqing Zhai obtained his PhD from King's College London, UK. He is currently a research fellow in science education at the National Institute of Education, Singapore. Junqing's doctoral thesis explored the professional practices of Botanic Garden Educators, in particular their pedagogical approaches that engage visiting students. Currently, he is working on a research project which investigates primary teachers' enactment of formative assessment in the context of inquiry-based science classrooms.

Index

K.C.D. Tan and M. Kim (eds.), *Issues and Challenges in Science Education Research: Moving Forward*, DOI 10.1007/978-94-007-3980-2,