Explorations in the Learning Sciences,
Instructional Systems and Performance Technologies

Chrystalla Mouza
Nancy Lavigne *Editors*

Emerging Technologies for the Classroom

A Learning Sciences Perspective

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Editors
Chrystalla Mouza
School of Education
University of Delaware
Newark, USA

Nancy Lavigne
School of Education
University of Delaware
Newark, USA

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Foreword

The first issue of the *Journal of the Learning Sciences* (*JLS*) was published in early 1991. The journal's mission has always centered on advancing our understanding of learning in real-world situations and of promoting learning in such venues. A key aim of the journal has also focused on identifying the roles that technology can play in promoting deep and lasting learning. As Founding Editor in Chief of *JLS*, I articulated the hopes of the community in my introductory editorial message published in the first issue. Our research community believed that we could create new methodologies for studying learning in real-world situations. Such methodologies would allow us to advance a science of learning more appropriate than traditional learning research for dealing with the education of our young people. We believed, too, that as we better understood processes involved in learning, we would, in parallel, be able to design and test new curricula, learning resources, materials, software, and ways of managing classrooms that could transform the opportunities young people had for learning. Armed with new methodologies and a knowledge base oriented towards design, we aimed at drawing and engaging more of the population in learning. We had an abiding hope and trust that computing technologies were a vehicle for promoting such learning. This was before widespread use of the Internet, before many families owned a personal computer, before many computers were adopted in schools, before commercial software was available for navigating the Internet, and before "World Wide Web" was a household term. In fact, the phrase may not even have yet been coined. Ultimately, we hoped that such work by members of the learning sciences community would play a role in redefining and redesigning the institution called "school."

So here it is, over 20 years later. I am delighted by the progress that has been made in research as a result of undertaking the core mission of the learning sciences. Moreover, the fast pace of hardware development and the advances made in the design of computing and communication technologies (both hardware and software) to effectively foster learning are thrilling. I am disappointed that more of what has been learned about promoting learning through technology use is not in place in schools. I am excited, however, to see that the series in which this volume is included is addressing that shortcoming and that this book, in particular, is designed as a forum for learning scientists and other scholars of instructional technology to share with education professionals what has been learned in the past 20 years. The authors are well-known scholars in the learning sciences and instructional technology fields, each with extensive experience working with K-12 teachers and students. The lessons they learned as a result of these collaborations provide useful insights for teachers, administrators, and researchers that can be tested, evaluated, and refined.

The volume *Emerging Technologies for the Classroom: A Learning Sciences Perspective* is designed to inspire education professionals in using both well-established (e.g., computer labs and classroom laptops) and innovative (e.g., smartphones and tablets) technologies in ways that address learning challenges or problems, and promote effective learning. These technologies are integrated into environments where learners (a) grapple together with difficult ideas and how these ideas apply in real-world situations, (b) have opportunities to test their ideas and see what transpires, (c) refine their ideas with peers or mentors and try again, and (d) obtain feedback from others as they make sense of the world around them and develop new skills and capabilities. In all instances, teachers play an active role as they engage with the students in putting forward and refining new hypotheses. In short, the volume presents environments where learning is both focused on skills and ideas that matter and happens as part of actively engaging in fascinating activities. In these environments, learners are excited enough about what they are doing, teachers feel they are making a real difference, and school becomes a place where learners want to go everyday.

In reading all of the chapters, I was struck by the number of themes that emerged. Indeed, I would have missed many of them had I restricted myself to reading chapters in a single section. Five major themes were evident throughout the volume:

- It is exceedingly difficult to promote learning by simply employing technologies. Use of technology must be thought out well in advance and refined over time to ensure its good use in promoting learning.
- Issues of equity and diversity must be at the forefront in designing and implementing technologies in learning environments.
- Multiple resources (i.e., technology, peers, teachers, mentors) can enhance students' learning in environments that involve design and construction (a particular genre of project-based learning).
- Moving regularly and fluidly from small-group to whole-class discussion and back again in ways that seem natural to the student community is an effective way of managing students' learning of the target knowledge and skills when engaged in design and construction.
- It is important to determine the kinds of collaborations and communities that will aid learning in a situation and how to promote such collaboration and community building, whether it involves online learning, use of mobile technologies, social networking sites, or what an electronic textbook might be like.

Overall, a major message is that to promote learning effectively, pedagogy needs to drive technology use. Chapter 2 makes this case very strongly, and many of the other chapters take it up and suggest ways of making that happen, even referring to the idea of “Curriculum 2.0” (Chap. 7)—the curriculum we could have if we think about the pedagogy that could promote learning objectives and the ways technology can be used to make that pedagogical approach a reality. A related big message is that use of technology allows envisioning a curriculum in support of achieving more sophisticated learning objectives. In addition to content, such objectives focus on supporting learning of skills needed for successfully joining the twenty-first century workforce (e.g., collaboration, reflection, self-regulation) and participating as an active citizen.

One book cannot itself address all of the issues involved in bringing computing and communication technologies into classrooms to promote learning. I am hoping, however, that this volume, along with the other volumes in this series, will play a big role in making that happen more broadly. I am hoping, too, that teachers reading this volume will get together and create communities around addressing issues of using computing technologies to foster learning, perhaps even using some of the technologies discussed in the volume to promote both community and idea development and sustain the discussion. May this volume and series be a catalyst for promoting more of the types of classroom activities researchers have uncovered as powerful for advancing learning.

Janet L. Kolodner
Georgia Institute of Technology
Atlanta, GA, USA

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Reviewers

Nancy Ares Warner School of Education, University of Rochester, Rochester, NY, USA, nares@warner.rochester.edu

Joshua Danish School of Education, Indiana University, Bloomington, Indiana, USA, jdanish@indiana.edu

Heisawn Jeong Department of Psychology, Hallym University, Chuncheon, South Korea, heis@hallym.ac.kr

Rachel Karchmer-Klein School of Education, University of Delaware, Newark, DE, USA, karchmer@udel.edu

Steven McGee School of Education & Social Policy, Northwestern University, Evanston, IL, USA, s-mcgee@northwestern.edu

Kevin O'Neill Faculty of Education, Simon Fraser University, Burnaby, BC, Canada, koneill@sfu.ca

Debbie Denise Reese Center for Educational Technology, Wheeling Jesuit University, Wheeling, West Virginia, USA, debbie@cet.edu

Eileen Scanlon Institute of Educational Technology, The Open University, Milton Keynes, United Kingdom, e.scanlon@open.ac.uk

Brett Shelton Emma Eccles Jones College of Education and Human Services, Utah State University, UT, USA, brett.shelton@usu.edu

Florence Sullivan School of Education, University of Massachusetts, Amherst, MA, USA, fsullivan@educ.umass.edu

Jody S. Underwood Department of Education and Training Technology, Intelligent Automation Inc., Rockville, MD, USA, jody.s.underwood@gmail.com

Jie Yan School of Education, University of Delaware, Newark, DE, USA, jyan@udel.edu

Zacharias C. Zacharia Department of Education, University of Cyprus, Nicosia, CYPRUS, zach@ucy.ac.cy

Andrew Zucker The Concord Consortium, Concord, MA, USA, azucker@concord.org

Contributors

Robert Q. Berry III Curry School of Education, University of Virginia, Charlottesville, VA, USA

Karen Brennan Media Lab, Massachusetts Institute of Technology, Cambridge, MA, USA

Glenn Bull Curry School of Education, University of Virginia, Charlottesville, VA, USA

Albert Cavalier School of Education, University of Delaware, Newark, DE, USA

Cathy Cavanaugh College of Education, University of Florida, Gainesville, FL, USA

Jennifer L. Chiu Curry School of Education, University of Virginia, Charlottesville, VA, USA

Stephanie Corliss Division of Instructional Innovation and Assessment, University of Texas at Austin, Austin, TX, USA

Susan Courey Special Education Department, San Francisco State University, San Francisco, CA, USA

Deborah A. Fields College of Education and Human Services, Utah State University, Logan, UT, USA

Cecile Foshee Mary Lou Fulton Teachers College, Arizona State University, Tempe, AZ, USA

Libby Gerard Graduate School of Education, University of California at Berkeley, Berkeley, CA, USA

Christine Greenhow College of Education, Michigan State University, East Lansing, MI, USA

Yasmin B. Kafai Graduate School of Education, University of Pennsylvania, Philadelphia, PA, USA

Diane Jass Ketelhut College of Education, University of Maryland, College Park, MD, USA

Younsu Kim School of Computing, Informatics, and Decision Systems Engineering, Arizona State University, Tempe, AZ, USA

William R. Kjellstrom Curry School of Education, University of Virginia, Charlottesville, VA, USA

Jennifer Knudsen SRI International, Menlo Park, CA, USA

Eleni A. Kyza Department of Communication and Internet Studies, Cyprus University of Technology, Limassol, Cyprus

Teresa Lara-Meloy SRI International, Menlo Park, CA, USA

Nancy C. Lavigne School of Education, University of Delaware, Newark, DE, USA

James C. Lester Department of Computer Science, North Carolina State University, Raleigh, NC, USA

Jiahang Li College of Education, University of Maryland, College Park, MD, USA

Marcia C. Linn Graduate School of Education, University of California at Berkeley, Berkeley, CA, USA

Feng Liu College of Education, University of Florida, Gainesville, FL, USA

Ou Lydia Liu Educational Testing Service, Princeton, NJ, USA

Bradford W. Mott Department of Computer Science, North Carolina State University, Raleigh, NC, USA

Chrystalla Mouza School of Education, University of Delaware, Newark, DE, USA

Elizabeth Murray Center for Applied Special Technology (CAST), Inc, Wakefield, MA, USA

Hedieh Najafi Ontario Institute for Studies in Education (OISE), University of Toronto, Toronto, Canada

Brian C. Nelson School of Computing, Informatics, and Decision Systems Engineering, Arizona State University, Tempe, AZ, USA

Charles Patton SRI International, Menlo Park, CA, USA

Kenneth Rafanan SRI International, Menlo Park, CA, USA

Mitchel Resnick Media Lab, Massachusetts Institute of Technology, Cambridge, MA, USA

Jeremy Roschelle SRI International, Menlo Park, CA, USA

Jonathan P. Rowe Department of Computer Science, North Carolina State University, Raleigh, NC, USA

Kent Slack Mary Lou Fulton Teachers College, Arizona State University, Tempe, AZ, USA

James D. Slotta Ontario Institute for Studies in Education (OISE), University of Toronto, Toronto, Canada

Michele Spitulnik Contra Costa Jewish Day School, Lafayette, CA, USA

Kurt D. Squire Morgridge Institute for Research, University of Wisconsin-Madison, Madison, WI, USA

Phil Vahey SRI International, Menlo Park, CA, USA

Mark van't Hooft Kent State University, Kent, OH, USA

Keisha Varma College of Education and Human Development, University of Minnesota, Minneapolis, MN, USA

Tobin White School of Education, University of California at Davis, Davis, CA, USA

Chapter 1
Introduction to Emerging Technologies for the Classroom: A Learning Sciences Perspective

Chrystalla Mouza and Nancy C. Lavigne

Rapid advances in technology have revolutionized the way in which children learn, play, communicate, and socialize. Technological gadgets, mobile phones, and participation in social network sites are now fixtures of youth culture (Ito et al., 2008). These innovations, collectively referred to as digital technologies, have created a *new culture of learning* (Thomas & Brown, 2011). This new culture of learning is characterized by learning opportunities that take place primarily outside traditional educational forums and is significantly different from our existing school culture where there is a tendency to use technology to reinforce basic skills and traditional practices (Cuban, 2001; Sawyer, 2006).

Halverson and Smith (2010) have identified two types of digital technologies that help explain differences in school and out-of-school practices: technologies for learning and technologies for learners. *Technologies for learning* are generic tools that define learning goals, develop structures to guide students, and provide measures of learning outcomes regardless of motivation or the ability of individual learners. These types of technologies have proliferated in schools settings because they do not necessitate major changes in traditional school structures. In contrast, *technologies for learners* emphasize student agency by allowing users to select their own learning goals and the means that will help them achieve those goals. Because these technologies necessitate major changes in school culture, they have mostly proliferated in out-of-school contexts. Thomas and Brown (2011) argue that the new culture of learning created as a result of technologies for learners can be used to augment learning in other facets of education and stages of life. In other words, technologies for learners can be used as a bridge between formal and informal learning.

This volume provides contemporary examples of the ways in which educators can use both *technologies for learning* and *technologies for learners* to create effective learning environments that support student agency and serve as a bridge between

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C. Mouza (✉) • N.C. Lavigne
School of Education, University of Delaware, Willard Hall 219 D, 19716 Newark, USA
e-mail: cmouza@udel.edu; nlavigne@udel.edu

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learning in school and out-of-school settings. Collectively we refer to them as *emerging technologies*. The term emerging is used to encompass both technologies whose integration in classroom settings is now being investigated as well as technologies whose integration has been researched but not exhaustively. In all instances, the focus is on technologies that are viewed as having the capacity to significantly influence the processes and outcomes of teaching and learning. Such technologies include tools that help students visualize concepts, construct dynamic representations of emergent hypotheses, collaborate with others, reflect on their learning, engage in anytime/anyplace learning, become participants in virtual worlds, and create their own 3D products and computer games. The examples presented are guided by multiple conceptual and methodological traditions evolving from the learning sciences and instructional technology communities, as well as other communities doing important work on learning technologies (e.g., computer science and cognitive science).

Digital Technologies: Past and Present

Since the 1990s a massive amount of resources has been expended to create universal access to technology in schools. The underlying assumption fueling these investments is that use of technology in the classroom will transform teaching and learning. Despite the investment, researchers have consistently observed modest use of technology in most schools and classrooms (Cuban, 2001). In his seminal book, *Teachers and Machines: Classroom Use of Technology Since 1920*, Cuban (1986) articulated that despite popular interest, reformers' enthusiasm, and significant investments, computer technologies gained limited support from classroom teachers much like earlier technologies, such as radio and television. In his subsequent book, *Oversold and Underused* (2001), Cuban found that limited uses of technology in both K-12 and university classrooms persisted, even in Silicon Valley schools, which are situated in social and cultural communities characterized by advanced technological innovation. Cuban maintained that technological innovations that do not take the routines and "grammar" of school into account will continue to have limited impact on teaching and learning.

Collins and Halverson (2009) identify three strategies used to address technological innovations without disrupting traditional schooling norms and structures. Those include condemning, co-opting, and marginalizing. In *condemning*, schools react primarily to the risks rather than to the potential of technology and resort to banning types of technologies thought to pose a risk to existing instructional practices. Such technologies include Smartphones and other mobile devices that permeate students' lives in out-of-school contexts. In *co-opting*, schools focus on technologies that can support existing curricular outcomes and instructional organization, such as drill and practice software or integrated learning systems. In *marginalizing*, interested teachers create boutique innovations alongside the general school contexts where they can work with like-minded colleagues and students.

Acknowledging the challenge of technological innovation in schools, current theorizing argues for the need to shift our attention from technology and software alone to the design of learning environments that include a focus on the infrastructural, curricular, and classroom routine levels in addition to technology (Collins & Halverson, 2009; Means, 2010; Roschelle, Knudsen, & Hegedus, 2010). The chapters of this volume provide exemplars of how technology can be used in conjunction with infrastructural and curricular resources, as well as routine levels in both school and out-of-school settings, to create effective learning environments. Thus, we now turn our attention to describing the content of this volume, providing a window into emerging issues in technology and learning from a learning sciences perspective.

Overview of Emerging Technologies for the Classroom

To help readers gain a better conceptual understanding of how technology can be used to create effective learning environments, we have identified four classes of emerging technologies (see Fig. 1.1) and structured this volume in four corresponding parts. Below, we briefly describe each class of digital technologies and the associated examples presented in the volume. In identifying examples, we focused primarily on the intended outcome of the chosen technology rather than on the technology itself.

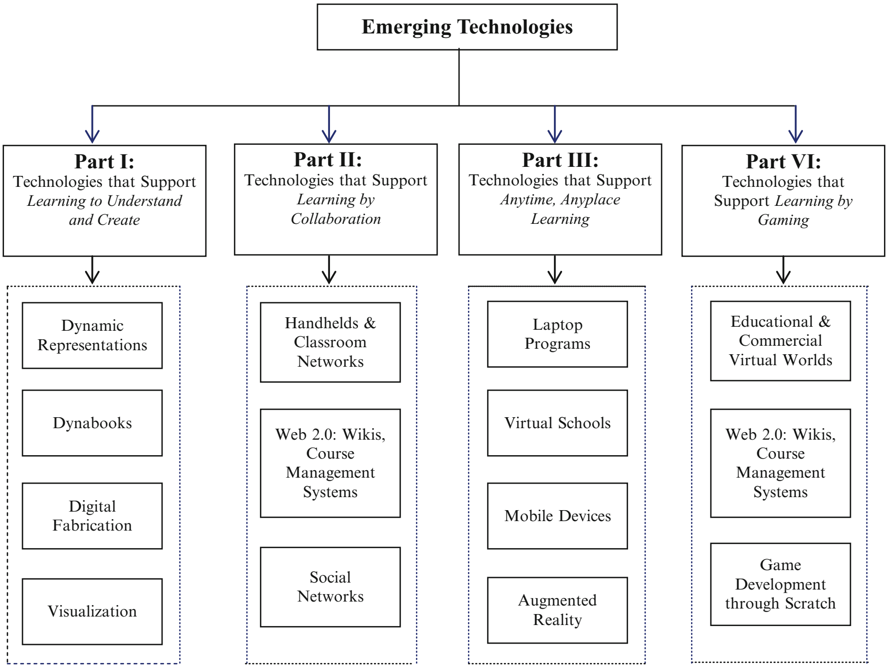

Fig. 1.1 Emerging technologies for the classroom

For example, the intended outcome of Augmented Reality games (Chap. 12) is to support mobility and bridge school learning with out-of-school contexts. Even though this example utilizes game-based technologies, the overall objective is to support anytime, anyplace learning, which is the primary theme of Part II. Such overlap characterizes other chapters as well.

Part I: Technologies That Support Learning to Understand and Create

Educational research has demonstrated that deep understanding occurs when students actively construct knowledge for themselves by engaging in real-world activities and by reflecting on their experiences (Krajcik & Blumenfeld, 2006). The value of digital technologies is precisely that they can provide students with real-world tasks (Papert, 1993). They can do so in ways that enable students to visualize abstract concepts (Edelson & Reiser, 2006; Konold & Kazak, 2008), which are typically difficult to understand. Alternatively, students can build their own models using 3D software, design their own products and inventions, and develop a range of digital artifacts as they engage in real-world problem solving. A wide range of technologies are available for supporting depth of understanding including dynamic tools that enable students to visualize the effect of manipulating variables (e.g., TinkerPlots), graphical tools that make salient the structure of students' thinking (e.g., concept mapping), computational or diagnostic tools that provide students with immediate feedback (Lantz-Andersson, Linderoth, & Säljö, 2009), modeling software that allow students to draw and design 3D objects, and digital fabrication technologies that enable students to visualize the transformation of digital representations of objects into physical prototypes (Bull & Garofalo, 2009). In this volume, we highlight four examples of technologies and learning designs that are used to support deep understanding. A brief summary of each example is presented below.

In Chap. 2, Vahey, Knudsen, Rafanan, and Lara-Meloy discuss how dynamic representations that embed mathematical relationships in manipulable objects can foster deep understanding of mathematics. Vahey and colleagues describe the notion of a curricular activity system approach, which deeply integrates learning progressions, professional development, curriculum materials, and software. With roots in Activity Theory (Engeström, 1987), a curricular activity system provides a framework for analyzing how cognition and learning are mediated by historically and culturally constituted tools. Two curricular activity systems are presented in the chapter that integrate dynamic representation tools, such as SimCalc and Geometer's Sketchpad, with curriculum and professional development to engage students in meaningful mathematics, resulting in deeper learning and greater equity.

In Chap. 3, Roschelle, Courey, Patton, and Murray focus on how the framework of Universal Design for Learning (UDL) can be used to design *Dynabooks*—digital books that are sensitive to the needs of all learners as they engage in sense-making, expression, and inquiry in challenging domains. UDL directs our attention to multiple representations, supports for students' action and expression, and ways to engage diverse students with material. Roschelle and colleagues discuss how a UDL approach has been developed in Dynabooks for reading, science, and mathematics and identify some key challenges going forward, as well as lessons learned for educators.

In Chap. 4, Chiu, Bull, Berry III, and Kjellstron discuss how students can use digital fabrication technologies to quickly prototype ideas and create sophisticated designs. Digital fabrication uses next generation computer controlled manufacturing systems to translate electronic designs into 2D and 3D physical objects. The chapter discusses how digital fabrication can help students in school-based and out-of-school settings create designs that satisfy mathematics and science-based criteria and constraints. Examples presented include the design of (a) a skyscraper with specifications and constraints of shapes, volume, and surface area; (b) architectural landmarks with specifications of surface area and volume; and (c) packaging with surface specifications connecting geometry and algebra. These creative designs encourage students to imagine, invent, collaborate, and construct solutions to complex and authentic problems that serve as the foundation of future STEM learning.

In Chap. 5, Gerard and colleagues focus on the use of visualization technologies in the context of the Web Based Inquiry Science Environment (WISE). WISE (http://wise4.berkeley.edu) places visualizations in an inquiry oriented learning environment that embeds scaffolding to enhance students' thinking about and with visualizations such that deep understanding does occur. Visualizations in WISE include but are not limited to interactive molecular level simulations, Flash and Java animations, graphs generated by students, data displays collected by sensors, data tables, diagramming, drawing, animation tools, idea managers, and video. The chapter illustrates that the power of these visualizations to improve student understanding depends largely on the teacher and not the technology alone. Specifically, the authors provide two exemplars of professional development programs that focus on teaching with visualizations. The programs differ in intensity but follow the same basic philosophy and demonstrate that the more intense professional development approach results in more effective teacher implementation of visualizations and greater student learning gains. The authors identify specific strategies that other educators can use to improve students' knowledge integration with interactive visualizations.

Part II: Technologies That Support Learning by Collaboration

In recent times, educational researchers have placed increased emphasis on a situative view of knowledge and learning as a means of helping students understand how what they learn in school applies to real-life situations (Greeno, 2006). The situative perspective moves away from the individual learner and focuses on activity systems. An activity system is defined as a complex social organization that contains learners, teachers, curricula, and technologies (Greeno). This approach to learning emphasizes social interaction and participation in a community of practice that embodies the desired beliefs and behaviors (Lave & Wenger, 1991). Guided by the situative view of learning, learning scientists have long studied the ways in which technology can bring learners together and support the social construction of knowledge.

Part II of the volume examines ways in which software, networked technologies, and emerging Web 2.0 tools, such as wikis and social networking sites, can support collaborative learning across time and space. The primary characteristics of such technologies are user-generated content and user participation, which provide the basis for the social interactivity (Chap. 8, Background). According to Thomas and Brown (2011) the success of Web 2.0 tools is largely attributed to the combination of the personal and collective; they enable users to post their ideas and interests on a personal space while also creating connections with others who may share similar interests. Contributing chapters discuss how such tools facilitate new ways of collaboration and interaction; forms of coaching and feedback; and opportunities for creative thinking, reflection, and civic engagement within online communities of learners. Collectively, these chapters provide models for how to "marry structure and freedom" to create novel learning environments that help people learn both *from* one another and *with* one another (Thomas & Brown).

In Chap. 6, White examines novel forms of mathematics teaching, learning, and classroom interaction supported by local networks of handheld calculators and computers. Classroom network tools bring new possibilities for classroom interaction because of their ability to distribute information rapidly and allow students to exchange ideas and construct shared artifacts. Three exemplars of interactive classroom activities supported by networked handheld devices are presented. The first is illustrative of a broad class of activities oriented toward engaging all students in a shared focus on dynamic mathematical representations collectively constructed from contributions sent through each student's device. The second exemplar involves linking the devices of smaller groups of students to facilitate collaborative problem solving. The third design merges these two approaches, using a classroom network to integrate and fluidly shift between small- and whole-group instructional activities. These exemplars demonstrate the potential of networked handheld devices to support the teaching and learning of mathematics through collaborative activities.

In Chap. 7, Slotta and Najafi describe a set of Web 2.0 tools that support collaboration and interaction. They also advance a new theoretical model of pedagogical design called, Knowledge Community and Inquiry (KCI), derived from the theoretical tradition of learning in knowledge communities. Two exemplars are presented in this chapter illustrating the application of Web 2.0 tools within the KCI instructional framework. The first exemplar employs a wiki to coordinate a recurring graduate seminar offered at a university, organized as a knowledge building community. Findings indicated that the wiki played a powerful role in supporting a collaborative design where students created their own content and organization. It also provided a context for rehearing and experiencing the ideals of learning as a knowledge community. The second exemplar focuses on a high school climate change curriculum that implements the KCI model, supported by a content management system. Findings indicated that students created an impressive knowledge base that could be used as a resource in subsequent inquiry activities. Both exemplars illustrate the importance of applying theory-driven pedagogical models in the design of curriculum that takes advantage of collaborative Web 2.0 technologies.

In Chap. 8, Kyza also discusses how networked technologies and Web 2.0 tools can support collaboration and reflection among students in support of twenty-first century skills. Two exemplars of networked technologies are presented. The first is a web-based learning and teaching software called STOCHASMOS, designed to support students' inquiry and reflection during collaborative learning explorations of data-driven scenarios. Findings indicated that STOCHASMOS was effective in supporting students' collaborative development of evidence-based explanations and reflective inquiry in science. The second exemplar focuses on the use of wikis within pedagogical activity sequences that can support collaborative knowledge building. Findings from this work demonstrated that the wiki and the task setup provided opportunities for productive dialogues among students and the building of intersubjectivity. Kyza also identifies areas of fruitful research that can advance our understanding of using networked technologies and Web 2.0 tools to support teaching and learning.

In Chap. 9, Greenhow and Li discuss the role of social networks in supporting peer collaboration and civic engagement, within formal and informal learning environments. For the purposes of this chapter, social networks consist of web-enabled services through which individuals can maintain existing connections with people they already know. Two exemplars of social network sites that support collaboration and civic engagement are presented and implications for educators and researchers are discussed. The first exemplar focuses on *Remix World*, a social network site created through the Digital Youth Network project in Chicago to support a learning ecology across school, home, and communities. The project seeks to provide learners with new media literacy experiences, help them create high quality new media products, and provide a public space to highlight their accomplishments. The second exemplar focuses on *Hot Dish*, an open-source social networking application aimed at engaging youth in information sharing, collaborative knowledge building, and civic engagement around environmental science and climate change issues. A set of questions that is expected to drive the research in the next decade concludes the chapter.

Part III: Technologies That Support Anytime, Anyplace Learning

One-to-one access to technology, often called ubiquitous computing, is regarded as the first step towards the transformation of teaching and learning (Pea, 1993). As a result, several large-scale initiatives have already focused on providing students with access to individual laptop computers or other types of mobile devices. Further, children appear to be one of the largest new user groups of mobile technology such as phones, laptops, or electronic devices (Druin, 2009). A recent report by Joan Ganz Cooney Center (Shuler, 2009) argues that these types of technologies can (a) support anytime; anyplace learning; (b) reach underserved youth; (c) improve social interactions; and (d) support a more personalized learning experience. Yet, the potential of those tools to enhance academic teaching and learning has been under-developed in the literature. Part III of the volume examines the educational potential of ubiquitous and mobile technologies to enhance student learning. Contributing chapters explore the possibilities of new forms of learning afforded by these devices within a classroom setting as well as their potential to extend learning beyond the classroom walls. Further, contributing chapters examine the potential of virtual schools to facilitate anytime, anyplace learning.

In Chap. 10, Mouza and Cavalier review the literature on the ways in which one-to-one laptop programs can change traditional learning environments in K-12 schools. They also present examples that illustrate ways in which teachers and students use laptops to bolster student technological literacy, transform the quality of instruction, and enhance student learning outcomes. These examples are drawn from a longitudinal investigation focusing on the design, implementation, and outcomes of a laptop initiative for students with learning disabilities in a career and technical education high school in the U.S. In their analysis, Mouza and Cavalier point to the need for effective professional development and support that is tailored to teacher needs and address classroom management concerns related to laptop initiatives. They also point to the need of further research on the benefits of laptop programs for student learning, particularly for students with disabilities who have traditionally struggled to succeed academically.

In Chap. 11, Cavanaugh and Liu examine online education at the middle school level. Specifically, they report on recent trends associated with online instruction at this level, the alignment of online learning with the cognitive needs of adolescents, and quality indicators of online courses. Subsequently, Cavanaugh and Liu present an exemplary online program for middle school students incorporating quality indicators identified in the literature, and report on the factors that contributed to the students' success in the online environment. Finally, they offer recommendations and insights gleaned from their work on how to design and teach online courses as middle school offerings expand into the mainstream of education.

While Chaps. 10 and 11 focus on how to promote anytime, anyplace learning through more established forms of technology, in Chap. 12 van 't Hooft discusses emerging forms of wireless mobile technologies and ways in which they can support learning in different contexts—both real and virtual. Three exemplary uses of mobile learning are presented that illustrate the pedagogical value of mobile technologies. The first exemplar discusses *Frequency 1550*, a mobile learning game that uses Global Positioning System and Ultra Mobile Telephone System technologies to let teenage students actively learn about the history of medieval Amsterdam by combining real and digital worlds. The second exemplar is *MyArtSpace* (Vavoula, Sharples, Lonsdale, Rudman, & Meek, 2007), which uses a combination of Smartphones and personal web space to provide a focused learning experience that provides essential links across different settings such as the classroom and a museum. The third exemplar discusses the *GeoHistorian Project,* which helps K-12 students think like historians by creating digital stories of local historical sites that can be accessed on the Internet or through Smartphones equipped with bar code readers. The chapter concludes by identifying administrative, pedagogical, and technological changes that need to be instituted in K-12 settings in order to take advantage of the affordances that mobile technologies provide for teaching and learning.

In Chap. 13, Squire discusses a different form of mobile learning centered on Augmented Reality (AR) games. Squire argues for an emerging pedagogical model in which mobile media are used to personalize learning experiences and connect schools with their local communities. Three exemplars of AR gaming curricula are presented. The first exemplar, *Saving Lake Wingra*, is a place-based AR curriculum unit designed around Lake Wingra in Madison WI, which helps students reason with data, make decisions, and acquire higher order thinking skills. The second exemplar, *Mentira*, is an AR game designed to introduce college students to Mexican–American culture and use of Spanish language in context. The third exemplar, *Mobile Design Workshop*, describes a semester long high school course in which students use a variety of devices in classroom practice and ultimately design a collaborative AR game about their community. These examples illustrate how mobile media can be used to connect learning to place, to build and extend interests, and engage learners in a range of complex, authentic learning activities. Squire argues that challenges associated with the use of mobile media are social rather than technical and identifies future areas of fruitful research in mobile learning.

Part IV: Technologies That Support Learning by Gaming

Game-based learning has recently gained increased momentum among learning sciences researchers. Games are important because they embody many principles associated with how people learn; they are immersive, they require players to have goals and make frequent decisions, they adapt to each player, and they unfold within the context of a community that supports the social dimension of learning (Van Eck, 2006). This social dimension of learning is critical because it makes it possible for players to experience the ways a particular discipline thinks about and solves problem as well as adopt a certain set of values that characterize a specific practice (Shaffer, Squire, Halverson, & Gee, 2005).

Although games have been primarily popular in out-of-school settings, there are different approaches that can facilitate their integration into more formal educational settings. The first approach focuses on the integration of commercial games into the curriculum (Van Eck, 2006). In this approach, gaming is used primarily to advance skills deemed important in an information-based culture such as technological literacy, critical thinking, creativity, problem solving, as well as interpersonal and leadership skills (see Chap. 16 for an example). A second approach focuses more explicitly on specific gaming content, helping students learn materials in a more innovative way (Oblinger, 2006; see Chaps. 14 and 15 for examples). Yet a third approach looks at the educational potential of having learners create their own games through accessible visual programming environments, such as Scratch (see Chap. 17 for an example). In all approaches, learners typically work together in the virtual world of the game and in the social community of its players (Shaffer et al., 2005).

Within the learning sciences, several game-based environments and lines of research have emerged that examine the ways in which games can support both academic learning skills and other forms of scientific and digital literacies valued in the twenty-first century. Part IV of the volume investigates ways in which we can use games to support how students learn in both formal and informal settings. Contributing chapters address ways in which teachers can design curricula around existing games, how to teach technology literacy practices, and how to help students think creatively and become both consumers and producers of digital media.

In Chap. 14, Nelson, Ketelhut, Kim, Foshee, and Slack present an overview of design approaches for creating virtual worlds based on cognitive-processing theory, focusing on the aspects that improve learning and motivation in students. They also present two early exemplar projects that are exploring the use of multimedia design principles in the design of virtual worlds. The first exemplar is situated in *SAVE science*, a virtual world-based model for assessment of middle school science learning. The second exemplar explores the role of multimedia principles in the design of a virtual world called *SURGE* (Scaffolding Understanding by Redesigning Games for Education). The SURGE project incorporates design elements found in casual physics-based computer games into learning-based virtual worlds in order to help middle and high school students connect their learning gained through games with more formalized physics concepts, representations, and vocabulary. Insights gleaned from these experiences are used to offer recommendations for the design of virtual worlds that can support student learning in K-12 settings.

In Chap. 15, Lester, Rowe, and Mott describe a different form of virtual worlds, called narrative-centered learning environments, and their promise to serve as a motivational force that can support K-12 STEM education. In particular, Lester and colleagues present Crystal Island, a narrative-centered learning environment aimed at supporting middle grade science education through interactive science mystery. They also identify connections between motivational factors, student learning, and engagement associated with Crystal Island. The chapter concludes with a description of next steps for the field as well as recommendations for researchers and practitioners interested in creating or incorporating narrative-centered learning environments into their classrooms.

While Chaps. 14 and 15 describe theory-driven virtual worlds designed by researchers, in Chap. 16 Fields and Kafai describe a commercial type of virtual world and the opportunities it provides in support of student creativity and creative play. Specifically, Fields and Kafai focus on *Whyville.net*, an open virtual world for tweens (children on the cusp of adolescence, aged 9–13). They also provide three forms of exemplar creative play: Avatar design, creative language play through flirting performances, and cheat designs for knowledge building. Further, the authors consider what these forms of creative play mean for designing for creativity and using virtual worlds in local educational contexts, particularly in light of discourses of safety and protection.

Brennan and Resnick conclude this section in Chap. 17 by shifting the conversation from children as mostly consumers of games and virtual worlds to children as designers of interactive media. In particular, Brennan and Resnick argue that as young people design interactive media, they go through an iterative process of imagining, creating, playing, sharing, and reflecting. They provide exemplars of young people using the Scratch visual programming environment to imagine, create, play, share, and reflect on their own interactive media with support from the Scratch online community. Future areas of research are identified and implications from this work are drawn for supporting design activities within formal educational settings.

Future Direction

Discussing technology and learning more than a decade ago, Pea (2000) wrote: "… technology change is proceeding at an exponential pace, and outstripping the capacity of society and social institutions, including schools, to deal with its ramification" (p. xxii). This excerpt exemplifies even more the rapid advances of technology in society today, making it difficult for schools and teachers to keep pace. Although schools are fairly resilient to change, they do respond to technological advances though not as quickly as we would like. With learning occurring as much in out-of-school settings as in traditional school settings, however, boundaries are blurring making it necessary to create new avenues for curriculum development, new forms of teaching and learning, and new ways of organizing how students and teachers interact (Collins & Halverson, 2009). Examples of such innovative practices or learning "edges" (Hagel & Brown, 2005) already exist and have been described in this volume, providing a resource for thinking about current issues and concerns revolving around technology enhanced learning. The challenge lies in moving those edges to the "core of formal schooling" (Brown, 2009, p. x). We hope that this volume will stimulate a discussion among researchers, policy makers, and educators of how to make this move happen.

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Part I
Technologies that Support Learning to Understand and Create

Chapter 2
Curricular Activity Systems Supporting the Use of Dynamic Representations to Foster Students' Deep Understanding of Mathematics

Phil Vahey, Jennifer Knudsen, Kenneth Rafanan, and Teresa Lara-Meloy

Julia and Paloma are in mathematics class, learning for the first time about the mathematical idea of slope. In stark contrast to many students' experiences, eyes glazing over as a teacher has them recite and memorize $(y_2 - y_1)/(x_2 - x_1)$, Julia and Paloma engage in a heated debate about how to make a character they see on screen run faster. Julia says that to make an onscreen runner move more quickly, they have to extend the line on a position graph (Fig. 2.1). Paloma says that extending the line will make the runner go longer but not faster. As the two students debate, they each manipulate the graph to explain their reasoning. Finally, they decide they should each try to make the runner move as fast as they can. Julia extends the current line as far as she can, and clicks the *Play* button. Although they are not sure whether the runner is going faster, they both agree that she is not going very fast. "Fine, you have a try," Julia says. Paloma moves the line so it is very steep, going off the top of the graph while still very close to the vertical axis. When Paloma clicks the *Play* button, both students are quiet for a second and then begin to laugh. "Did you see how fast she went?" Julia says through her laughter. "Wow" is all Paloma can say.

As Paloma tries to figure out what she did, she notices that not only was the run over very quickly but that the timer stopped at 2 s, with the endpoint of the graph aligned with 2 s along the horizontal axis. Also, the runner was stopped at 50 m, and the endpoint of the graph is aligned with 50 m along the vertical axis. "Hey," says Paloma, "look at this: My graph says the runner should go 50 m in 2 s. Nobody can really run that fast, can they?" "I don't think anybody can run that fast, but how does the graph say that?" asks Julia.

In the ensuing conversation Paloma and Julia begin to develop the intuitive idea that the steeper the graph, the faster the runner. Going even further, they see that this is because a steep graph "covers" a lot of distance in a very short time. In future

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P. Vahey (✉) • J. Knudsen • K. Rafanan • T. Lara-Meloy
SRI International, Menlo Park, CA, USA
e-mail: philip.vahey@sri.com; jennifer.knudsen@sri.com; kenneth.rafanan@sri.com; teresa.lara-meloy@sri.comteresa.lara-meloy@sri.com

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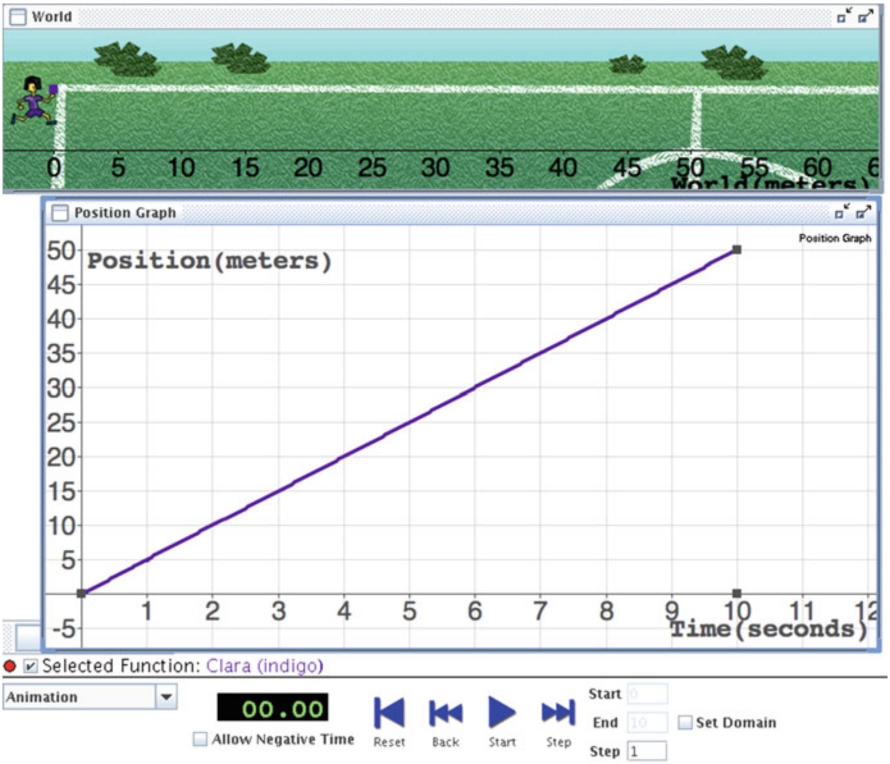


☑ Selected Function: Clara (indigo)

☐ Allow Negative Time

Start 0
End 10
Step 1

Fig. 2.1 A dynamic-representation environment, SimCalc Mathworlds®, with a "world" that shows a runner on a soccer field, a position graph, a timer, and a set of animation buttons

classes, this intuitive notion that a steeper graph represents covering more distance in less time will be used first to develop a formal measure of speed and then as the basis for the more general notion of slope. By the end of the unit, these students will know not only that the slope formula is $(y_2-y_1)/(x_2-x_1)$, but also *why* this is the formula and *how* to apply it in a variety of contexts.

While hypothetical, this account is based on experiences found in classrooms in which dynamic representations are being used to teach students about rate, proportionality, and slope. These experiences contrast markedly with what we call the *symbols first* approach that currently dominates current mathematics instruction. In the *symbols first* approach, students manipulate symbols as a way to engage in mathematics and presumably to learn the concepts underlying these manipulations. Decades of research have shown that the symbols first approach to teaching mathematics does not serve the majority of our students well (Healy & Hoyles, 2000; Stacey, Chick, & Kendal, 2004), as this approach leads students to view mathematics as an arbitrary set of rules to be memorized and regurgitated on command (Muis, 2004), instead of viewing mathematics as a system in which the manipulation of symbols represents an underlying logic that can be used to model phenomena in the world. Furthermore, the symbols first approach has resulted in great inequities in mathematics learning: Students from ethnic, cultural, and language minorities, as well as students who come from low socioeconomic status (SES) households, have been particularly underserved by traditional mathematics education (Education Trust, 2003a, 2003b).

Dynamic-representation environments provide a way to break free from the symbols first approach, fostering interactions such as those between Julia and Paloma. By leveraging now-common digital and computational technologies, we can engage more students in more meaningful mathematics, resulting in deeper learning and greater equity.

Background

The claim of increasing learning and equity is more than just a future promise. For approximately 20 years, the goal of research in dynamic representations in general and the SimCalc project in particular has been to ensure that all learners have the opportunity to learn complex and important mathematics. For SimCalc, this goal is expressed in the mission statement "democratizing access to the mathematics of change and variation" (Kaput, 1994). A series of studies have found SimCalc to be successful in meeting the needs of a diverse set of students and teachers. Ninety-five seventh-grade teachers and their students in varying regions in Texas participated in a randomized controlled experiment in which they implemented a SimCalc-based 3-week replacement unit. The results showed a large and significant main effect with an effect size of 0.8 (Roschelle et al., 2010). This effect was robust across a diverse set of student demographics. Students who used the SimCalc materials outperformed students in the control condition regardless of gender, ethnicity, teacher-rated prior achievement, and poverty level (Fig. 2.2). In addition, a study in Florida, the SunBay Digital Math project, used the same materials but with no control group. The SunBay project replicated the gains found in the Texas study (Fig. 2.3). In both Texas and Florida, on simple proportionality items, students using SimCalc materials gained about the same as students in the Texas control condition. These gains are shown in Fig. 2.3 as M1; these items were simple $a/b=c/d$, $y=kx$ problems, or questions calling for straightforward graph and table reading (often called "the basics"). However, on items that drew on more complex proportional reasoning, such as requiring a functions approach (e.g., in which students must map between a domain and range) or requiring reasoning across two or more representations, students who used SimCalc materials exhibited significantly stronger learning gains. These gains are shown in Fig. 2.3 as M2.

We attribute the success of these projects, which helped students to learn more complex mathematics while still learning "the basics," to two key features: the use of dynamic representations and the integration of the technology-based representations into an overarching *curricular activity system*. The curricular activity system includes professional development (PD), materials, and technology, all integrated to meet the needs of students, teachers, and schools.

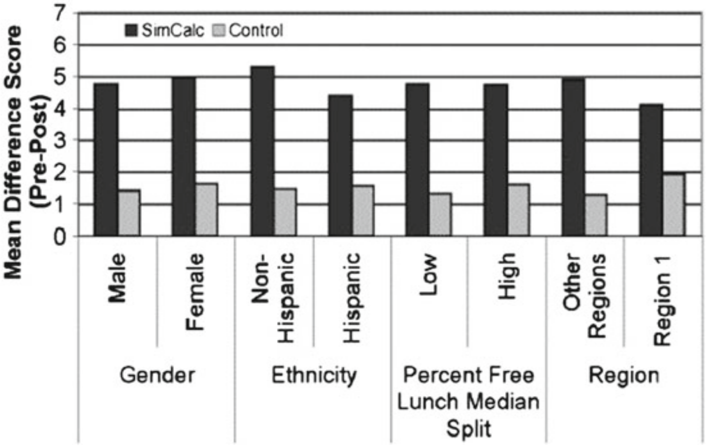


Fig. 2.2 Results from a randomized experiment showing SimCalc students outperformed control group students across a wide range of demographic factors

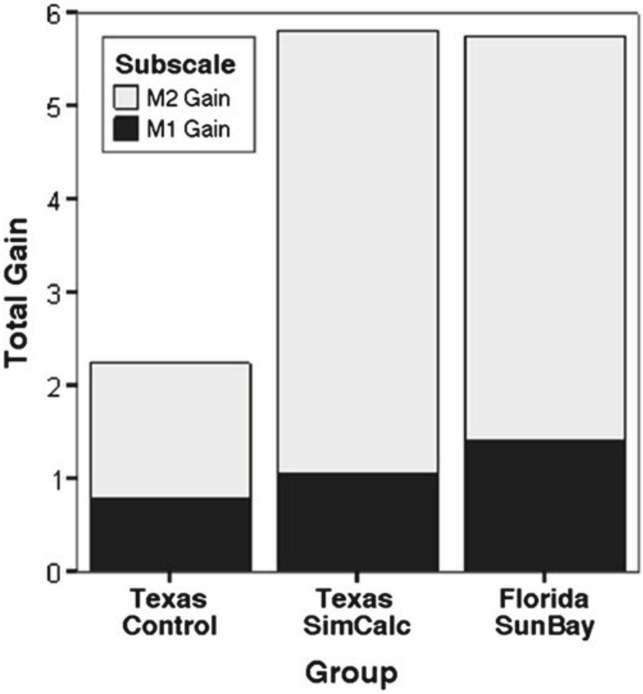
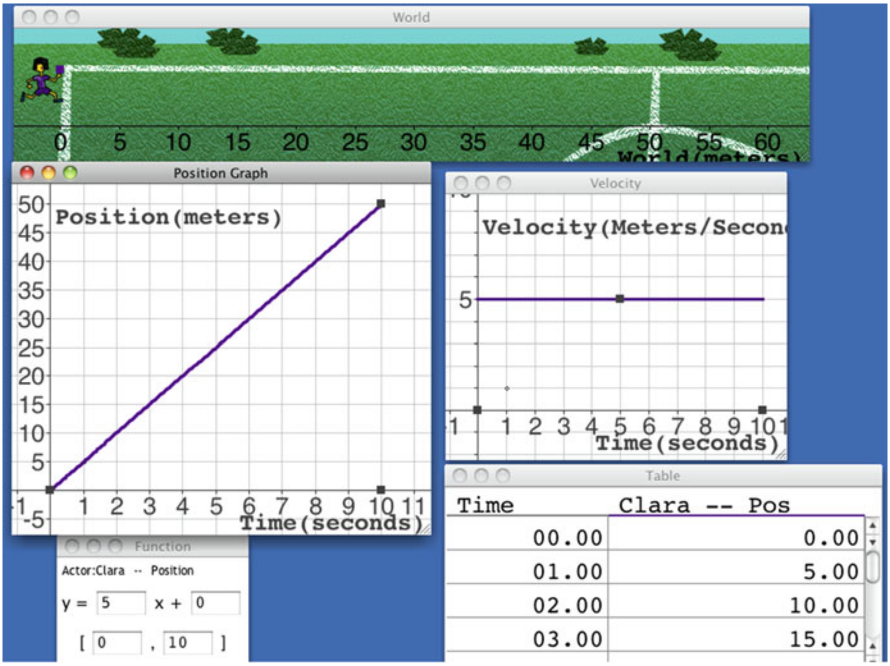


Fig. 2.3 A comparison of the SimCalc experiment and Florida SunBay implementation study showing similar learning gains



Actor:Clara -- Position

y = 5 x + 0

[0 , 10]

Time	Clara -- Pos
00.00	0.00
01.00	5.00
02.00	10.00
03.00	15.00

Fig. 2.4 A dynamic-representation environment, SimCalc Mathworlds®, with a “world,” a position graph, a function window, a velocity graph, and a table

In the remainder of this chapter, we present how a curricular activity systems approach can be combined with the use of dynamical representation environments to help a wide variety of teachers increase student learning for diverse student populations. To do this, we describe what we mean by dynamic-representation environments, discuss the benefits of such environments, and present evidence that these benefits may be especially strong for students who traditionally underperform in mathematics. We describe what we mean by *curricular activity system* and follow this with exemplars that illustrate how a focus on curricular activity systems leads to the design of materials usable by a wide variety of teachers.

What Are Dynamic-Representation Environments?

Dynamic-representation environments embed mathematical relationships in (typically digital) objects that the student can manipulate. Consider a set of dynamic representations that may be available to understand the motion of a runner. Paloma and Julia were using a runner, timer, and position graph, but the environment could offer other representations as well (Fig. 2.4). For instance, increasing the slope of the line on a position vs. time graph could also (a) increase the height of the corresponding line on a velocity vs. time graph, (b) modify an algebraic expression of the motion, and (c) modify the entries in a table showing the position of the runner during the motion.

Enabling students to manipulate mathematical objects, and supporting them in predicting, evaluating, and understanding the corresponding changes in the environment, are at the heart of effective uses of dynamic representations. Although the algebraic symbol system is a key representation in this environment, it is not the primary focus, nor is it the starting point of the mathematical analysis. Instead, having students gain an understanding of the mathematics through an analysis of the behavior of a set of linked representations is the primary focus of a rich mathematical activity.

This manipulation typically is controlled via specific hot spots carefully chosen by designers of the environment (Moreno-Armella, Hegedus, & Kaput, 2008). Manipulating a single hot spot varies one specific mathematical relationship while other mathematical relationships remain invariant. These hot spots may be chosen in a way that is counter to design principles for productivity applications because efficiency of action may take a backseat to mathematical clarity. For instance, in the SimCalc examples displayed in Figs. 2.1 and 2.4, the student cannot simply select the end point of a segment and drag it to an arbitrary place on the graph. Instead, one hot spot is used to change the height of the segment, and another is used to change the length of the segment; these hot spots correspond to a change in range (position) and a change in domain (time), respectively. Similarly, in Geometer's Sketchpad (GSP), a dynamic-representation environment for interaction with Euclidean geometry, students do not have access to the set of drawing tools and manipulations found in traditional drawing or presentation software. Instead, the students (or the curriculum designers) construct the geometric figures and drag hot spots to manipulate these figures in a manner consistent with Euclidean geometry (insofar as consistency is possible; see Goldenberg, Scher, & Feurzeig, 2008).

As students manipulate the environment through the use of hotspots, the environment constrains the actions allowed while providing feedback as to the mathematical relationships embedded in the environment (Ares, Stroup, & Schademan, 2009; Moreno-Armella et al., 2008). One implication is that student actions are constrained to those that are mathematically possible: in SimCalc, the student cannot create a graph that is not a function (e.g., it is impossible to place the same runner in two places at one time). Another implication is that results of student actions are propagated throughout the rest of the environment: in SimCalc, moving the starting point of an actor in the simulation instantly changes the equation, position graph, and table. This interplay between user and environment, in which the logic of mathematics is simultaneously explored and enforced, can be used to create environments that have well-understood benefits for learning.

Benefits of Dynamic-Representation Environments in Mathematics Education

We leverage four key benefits of using dynamic-representation environments in mathematics classrooms: (a) providing multiple representations for student understanding, (b) providing a shared focus of attention, (c) supporting the use of narrative as a representation, and (d) engaging students in the mathematics. We first describe these benefits individually, and then discuss how the combination can lead to democratization in student learning of mathematics, as the use of dynamic-representations environments can be especially beneficial to students who are traditionally underserved in mathematics class.

A core benefit of dynamic representation environments is the use of *multiple representations* to instantiate mathematical concepts. Almost by definition, multiple representations provide students with multiple perspectives on the same mathematical phenomena. For example, to make sense of a scenario in which two runners race, students can draw on the perceived speed of each runner's motion, the initial and final location of each runner, the value of the timer, comparisons of the function lines on the graph, and on how changes in one representation affects the others. The aggregate effect is to embed computational rules in perceptual systems, which re-represent complex relationships in ways that can be more easily perceived (Ainsworth, 2006). Although it is possible for the presentation of so many resources to be confusing and overwhelming, the evidence on student learning shows that when these representations are properly designed and scaffolded, students can integrate the information from them to build a more complete mathematical understanding (e.g., Mayer, 2005).

By providing a *shared focus of attention*, dynamic representations can be particularly powerful tools for supporting effective mathematical discourse. They can allow gestural and physical communication to supplement verbal and written symbolic communication, and provide meaningful feedback that is consistent with the mathematical phenomena under investigation (Moschkovich, 2008; Roschelle, Kaput, & Stroup, 2000).

Dynamic-representation environments are also well suited to introducing meaningful *narrative* into the mathematical learning experience (Sinclair, Healy, & Sales, 2009). Through the introduction of narrative, the mathematics becomes "about something" (such as the running of a race or the speed at various times during a trip) and moves away from being solely a set of abstract rules that are disjoint from any experience. In addition, the use of narrative grounds investigations in familiar settings, which enables students to apply their intuitive knowledge of the real world, while also providing them with a means by which learners can translate between the different representations. Through the use of narrative as part of the mathematical activity, students are able to engage in creative and fanciful stories, which can then link back to the mathematics under investigation (see Chap. 15 for additional benefits). Students from backgrounds that are underserved by traditional mathematics instruction (such as students from low-SES and language minority communities) can engage in complex narrative creation and analysis as they successfully learn complex and important mathematics (Zahner, Velazquez, Moschkovich, Vahey, & Lara-Meloy, 2012).

Dynamic-representational environments have also been shown to increase *student engagement* in mathematics. Key features already discussed, such as allowing students to directly interact with and manipulate mathematical objects, influencing the behavior of the mathematical environment, and constructing and evaluating narratives, all help to lessen the distance between the student experience and the abstract mathematical concepts. Furthermore, when leveraged in productive learning activities, these features can lead to feelings of curiosity, excitement, and challenge, emotions that most students rarely feel in traditional mathematics classes (Schorr & Goldin, 2008). By actively participating in the mathematics, students may even project themselves into the mathematical system, imagining themselves as part of the mathematical environment (Hegedus & Penuel, 2008). Because of this increased engagement, even students with a history of disengagement in mathematics class can interact with deep and important mathematics more productively and for a longer time than they typically do when using a traditional symbols first approach.

These benefits can accrue to allow for a very different type of mathematics classroom, one in which engaged students use narrative and representations in conjecturing, justifying, and explaining. This type of classroom is beneficial across a wide range of students and demographics. For instance, there is consonance between the literature on improving instruction for low-income students from nondominant linguistic backgrounds and the literature on the use of representationally rich technologies in mathematics (Vahey, Lara-Meloy, & Knudsen, 2009). Both bodies of research highlight the use of multiple representations, point to supporting students as they make connections among these multiple representations, and point to the importance of language-rich practices. Linked representations can provide a shared set of referents for students and teachers to explore: They can replay a motion or make changes in one representation to see the changes in the others (as in Fig. 2.1). Students have opportunities to use a wider range of verbal and nonverbal communication acts, such as pointing: “See, right here, the boy starts running faster.” Students also have opportunities to use academic mathematical language for a communicative goal (e.g., answering the question, Does “here” in the hypothetical example above refer to time or distance?). This multimodal and multisemiotic approach is consistent with recommendations for supporting mathematical discourse while developing vocabulary (Moschkovich, 2007; O’Halloran, 2003).

Although the benefits to using dynamic representations are well documented, the use of dynamic-representation environments is still rare in mathematics classrooms. While there are many economic and political reasons why schools may not have the technology infrastructure needed to effectively use these technologies, research shows that many mathematics teachers do not use computers in their teaching even in schools with available technology (Wachira & Keengwe, 2011). Many teachers are uncomfortable in using technology for teaching, are not sure of the most effective uses of technology, and feel constrained by accountability demands. In the next section, we discuss how an approach that goes beyond looking solely at the benefits of technology to consider the overarching *curricular activity system* can lead to an increased use of dynamic representations in the classroom.

Curricular Activity Systems

A *curricular activity system* approach (Roschelle, Knudsen, & Hegedus, 2010) deeply integrates learning progressions, PD, curriculum materials, and software, recognizing that these are all situated in a larger educational context that includes particular sets of people, conventions, and policy considerations. Our notion of a curricular activity system has its roots in Activity Theory (Engeström, 1987), which provides a framework for analyzing how cognition and learning are mediated by historically and culturally constituted tools.

Curricular activity systems help developers focus on activities. We think of an activity in terms of its objective for the participants, available materials, the intended use of tools, the roles of different participants, and the key things we want the participants to do and notice. But a focus on activities in this sense is not sufficient. While an activity may be well specified and be proven to have effective learning outcomes, it must fit into the wider context of the classrooms that are expected to engage in the activity. Considering the classroom context immediately leads to a cascade of questions: What do teachers need in order to realize these activities—what must the PD include? What are the material supports for the activities, including hardware and software that are available? Who are the students who will use the materials, and what are their special needs? A productive way to generate and think about such questions is through Cohen, Raudenbush, and Ball's (2003) framework in which the classroom learning environment consists of interactions between three primary resources: the content, the teacher, and the students. The scope of a curricular activity system can therefore be broadened to include how different aspects of a system can target each set of interactions.

Our introduction to this chapter illustrates an interaction between students and materials, showing how dynamic representations, embedded in learning activities, allow students to gather evidence for and then validate mathematical conjectures. To effectively support student–materials interactions, the materials must be carefully designed so as to be approachable by students with varying background in terms of prior achievement, past experiences, and reading levels, while also focusing students on the core mathematics to be learned.

We have found that teacher PD can play a key role in supporting the interaction between teachers and students, as well as between teachers and materials. A particularly effective way of supporting both sets of relationships simultaneously is by engaging the teachers with the materials in two phases. In the first phase, teachers approach the materials as though they are students. This allows them to experience the benefits of the dynamic representations in learning the mathematical content; otherwise, key aspects of the environment (such as analyzing the motion of a runner) may seem like an unnecessary waste of time. It also allows teachers to better understand and be prepared for the types of student reasoning they are likely to experience in the classroom. In the second phase, they approach the materials in their more familiar role of teacher. This allows them to explicitly link the materials to required standards and accountability measures, and provides time for them to consider how their own teaching practices can be leveraged to support student learning. Although using PD to address these aspects of the program may seem obvious, most traditional PD does not provide the time, activities, or content needed to help teachers use new materials and improve their classroom practice (Garet, Porter, Desimone, Birman, & Yoon, 2001).

The exemplars of curricular activity systems in the next section provide a sense of the specific design decisions that we have made in designing materials.

Exemplars

Exemplar 1: SimCalc

The SimCalc-based curriculum unit used in the Texas and the SunBay studies addressed core state standards as well as topics that were more challenging than those in the standards. The unit, *Managing the Soccer Team*, was originally developed to address Texas' seventh-grade standards on rate and proportionality and included multirate functions and the meaning of slope. It underwent minor revisions to meet the curriculum goals of teachers in Florida, but the core principles underlying the design remained the same. The 3-week unit was designed to replace the materials that teachers normally used to teach rate and proportional functions.

Beginning with simple analyses of motion at a constant speed, *Managing the Soccer Team* followed a learning progression that culminated in more complex topics. It addressed unit rate and proportional functions—topics from the seventh-grade Texas standards that are also core to Florida standards as well as the Common Core Mathematics Standards—and ended with multirate functions and an informal expression of the meaning of positive, negative, and zero slope.

By combining paper materials with guiding questions and SimCalc MathWorlds software files, the unit provided a structured exploration of algebraic representations through connections to real-world topics. Students had opportunities to use various motions and other "accumulation" contexts (distance was accumulated as a runner moved along; money was accumulated when increased at a given rate). *Managing the Soccer Team* presented soccer players running races and team buses traveling from one town to another, and students were to find speeds and write stories to explain patterns of motion. Nonmotion contexts included saving money when buying uniforms and predicting how much fuel vehicles would use, in miles per gallon.

Even with these decisions made, however, the curricular activity system approach highlighted significant decision points that still remained. We will address three key decisions that affected the ways in which teachers interacted with students: the form of the curriculum materials themselves, how teacher preferences for specific types of classroom interactions were scaffolded, and how the PD was used to prepare teachers for interacting with students during the unit.

Form of Materials

The actual curricular materials are typically the focal point of student–teacher interactions. Because of the centrality of these materials and because of the novelty of using dynamic representations in mathematics class, we decided that a traditional-looking set of paper materials would be the most productive form. The argument could be made that all materials should be embedded in technology, but we found that most mathematics classrooms do not have the infrastructure to provide all students with one-to-one computer access. Further, even if such access were available, at the time the authors wrote this chapter there were still benefits to using paper technology: students could take a workbook with them to complete homework in their afterschool program; teachers could move students around the classroom and to different groups on the fly without being concerned about moving technology; teachers were familiar with grading paper homework and assessments and would be more likely to take home paper workbooks to review student work; and many teachers in our studies had both an LCD projector and a document projector, enabling them to simultaneously display the dynamic representations and student work during class discussion. Although we expect that many of these constraints and benefits will soon change and that materials fully embedded in technology will soon be commonplace, we believe that changing the entire system at once, especially given the current state of technology in most schools, could delay the overall adoption of dynamic representations. Therefore, we introduced the key core innovation—dynamic representations—as the one novel approach in the materials and allowed teachers to use familiar paper workbooks in other aspects of the unit.

Teacher Preferences for Classroom Interactions

We have found that teachers are not likely to make significant changes to their general teaching style and routines to implement a short replacement unit with limited time for PD (see also Garet et al., 2001). Instead, they are more likely to shape their use of the materials to fit their styles and routines. We have also found, however, that engaging students in a routine of *predict*, *check*, and *explain* while using dynamic representations is very productive for learning. For example, students are asked to *predict* which of two runners will reach the finish line first. The students can run the simulation to *check* whether their predictions were correct. Students are then prompted to *explain* how their predictions matched or did not match what they observed in the simulation.

To meet teachers' need of maintaining much of their existing styles and routines while also introducing the routine of predict, check, and explain, we embedded all the important questions (including the predict, check, explain cycle) in the student materials. We have noticed that other materials often provide teacher guidance in the form of "lead a whole class discussion around the following questions." Instead, we embedded the questions in the student materials and provided the teacher with guidance on how to use the materials in leading a whole class discussion. Besides ensuring that all the important questions were in the student guide, this also gave teachers the ability to modify our suggested activity structure. Teachers could modify our suggestions (for instance, turning a whole-class activity into a small-group activity) while having the confidence that students would encounter all the important questions in the student materials. Instead of placing the burden on teachers to set up and carry out a sequence of questions that might be foreign to them, we made it possible for them to guide students through their workbooks in a way suited to their teaching style.

Professional Development

To meet district constraints on the amount of PD that could be offered, we administered a 3-day workshop. The workshop used a "teacher as learner" approach, providing teachers with the opportunity to experience our intended activities for themselves. The workshop leaders were able to point out the details of the learning progression and special features of the software and curriculum all along the way. During the unit run-through, the teachers were able to develop some comfort with the software and materials, and we provided technology advice to boost their confidence. More importantly, the teachers themselves and occasionally the workshop leaders would present the types of questions and reasoning that we would expect from students. By taking seriously these questions and lines of reasoning, teachers were able to become comfortable with the types of reasoning and questions they would be hearing from their own students.

Exemplar 2: Geometer's Sketchpad

Our second exemplar involves the use of GSP in a curricular activity system focusing on students' development of definitions for geometric similarity. The materials for the unit included premade GSP files and written materials that supported teachers in guiding students through making qualitative and quantitative definitions of the similarity of rectangles and parallelograms, contrasting, for example, the need for requiring only equivalent side-to-side ratios for rectangles with the need to have congruent corresponding angles for parallelograms. The GSP files enabled students to align geometric figures in ways that revealed their similarity or congruence and to collect data on changes in lengths of sides, as figures were scaled larger or smaller. In its first version, the unit did not use cross multiplication in finding missing sides in similar figures, reflecting the curriculum developers' belief that this algorithm is often misunderstood and misused by students at the middle school level. Partly as a consequence of this decision and partly for internal consistency, the terms "similar," "ratio," and "equivalent ratios" were used instead of "proportion" and "proportional" in the written materials.

During the PD session, teachers and a PD leader from the development team went through the unit, with the teachers playing both the roles of learners and of teachers of the materials. In both roles, teachers found troubling the lack of both proportion language and the cross multiplication algorithm. Many said they had already taught both these concepts, so it did not make sense to exclude the terms and procedure in the similarity unit. Furthermore, the district pacing guide stated that students should connect similarity with prior learning on proportionality. Although the PD leader explained the developers' position, the teachers believed that it was important to connect students' prior learning on proportionality to their work on similarity, as well as to conform to the district expectations.

The PD leader brought these concerns to the development team as it prepared to make final changes to the materials for classroom use. After much deliberation, the team decided to include a lesson on the language of proportion and connect this language to the language of similarity in the remainder of the unit. We did not, however, include cross multiplication; to include this algorithm while staying true to our philosophy of teaching would have required additional activities to foster understanding of cross multiplication. Adding such activities to the unit would have been a significant conceptual detour and would have required too many lessons for a reasonably sized replacement unit.

A key lesson from this experience is that a focus on a curricular activity system produces a set of supports not only for an intended activity, but also for the *relationships* among teachers, students, and materials. This requires flexibility on the part of curriculum developers. If we had seen our job as solely to best support our own ideas and hypothesized learning progression for similarity, and viewed teachers as implementers of these materials, we would not have changed the materials. Instead, we considered the importance of preserving relationships already formed among teachers, students, and materials in addition to the learning progression we had designed.

Although the use of dynamic representations is a core aspect of our unit, our view of the curricular activity system in relation to the instructional relationships in the classroom led to serious consideration of curricular issues that were only peripherally related to how students use the dynamic representations. Such considerations are consistent with our position that the use of representations must be situated in a larger context. Only when teachers' concerns are addressed will they feel compelled to use the materials, thus allowing their students to benefit from the use of dynamic representations.

This case also highlights the importance of considering the existing curriculum sequence as part of a local policy context—the environment in which the classroom is situated—even when a supplementary curricular activity system is being designed. The curriculum sequence, which is often mandated by a pacing guide (particularly in urban districts) or structured by an adopted textbook, is an outside-the-classroom factor that affects what is taught and learned in the classroom. Not all developers, of course, have the luxury of rewriting materials before localized implementation. But all curriculum developers can investigate the policy context—be it local or national—in which their materials can be used and adjust them accordingly. How to accomplish this task without compromising core intentions and beliefs is a design tension that needs to be resolved on a case-by-case basis.

Next Steps

For teachers and administrators, curricular activity systems provide a way to consider practical problems of choosing and implementing the kinds of technologies discussed in this chapter. For example, administrators will want to consider teachers' prior experiences with technologies and paper-and-pencil environments when choosing a mix of these for classroom use. They will want to consider current practices and choose or adapt programs that enable teachers to keep many current teaching moves while changing some—as in the predict, check, explain routine. Teachers can advocate for materials that suit their practices yet still challenge students, and they can advocate for technologies, such as those described, with affordances for a wide variety of students.

There is more to understand about curricular activity systems and their relationship to dynamic representations. While the relationship between materials—particularly technology—and students is a traditional focus of learning scientists, the cases described here bring up the need for balance between the intentions of teachers and developers and the needs of students. As we broaden our perspective, new questions arise; for example, what is the existing set of relationships among teachers, students, and materials into which the new system must fit? And what aspects of the system can we reasonably expect to change, and what aspects must we work within?

Our perspective on a curricular activity system moves us away from the view that a single factor (e.g., a technology, curriculum, or PD plan) can result in meaningful and widespread educational change. Instead, each factor must be considered with respect to the others and situated in an overarching context. In this chapter, we provided examples of how these different factors can be considered as part of an overall system. As the field moves forward practitioners, developers, and researchers must advance this line of thinking and better understand how local constraints, the broader policy environment, specific learning goals, and available resources interact, with the aim of creating learning environments that are widely used and widely effective.

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Chapter 3
Dynabooks: Supporting Teachers to Engage All Learners in Key Literacies

Jeremy Roschelle, Susan Courey, Charles Patton, and Elizabeth Murray

Textbooks and teachers are clearly among the most powerful influences affecting the mathematics that students learn (Schmidt et al., 2001). Presently, educational materials are in the midst of a major transition from print to digital media. This transition is primarily driven by declining state budgets available for purchasing print materials, by the increased popularity of all kinds of digital books available on mobile devices, and by the need to respond to new Common Core State Standards for Mathematics (http://www.corestandards.org/). If not carefully implemented, the global transition to digital materials could result in merely reproducing existing texts in a new medium. It could also result in a further fragmentation of mathematical thinking, as is occurring through popular "just in time" resources for students. For example, popular online videos now provide exactly the instructions students need to complete a particular problem with no particular concern for achieving broader and deeper connections across related problems, concepts, and representations.

With regard to mathematics education, we aim to design digital texts that help teachers to focus on mathematical thinking. By a "focus on mathematical thinking," we include teachers' role in (a) making sense of students' thinking, (b) helping learners to express multiple approaches to solving mathematical problems, (c) using representations and technologies insightfully to explore mathematical meaning, (d) structuring extended conversations with students around mathematical ideas, and (e) developing their own ability to reflect articulately on their own sense making.

J. Roschelle (✉) • C. Patton
SRI International, Menlo Park, CA, USA
e-mail: jeremy.roschelle@sri.com; charles.patton@sri.com

S. Courey
Special Education Department, San Francisco State University, San Francisco, CA, USA
e-mail: scourey@sfsu.edu

E. Murray
Center for Applied Special Technology (CAST), Inc., Wakefield, MA, USA
e-mail: bmurray@cast.org

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Seeing mathematical thinking as inclusive of comprehending, doing, reflecting on, and teaching mathematics has led us to think about a teacher or student's ability to engage with mathematical thinking as a twenty-first century *literacy*.

Consequently, we ask the question: how could the transition to digital media result in the co-emergence of new forms of resources and newly important forms of literacy? We focus on the possibility of digital resources that are true to the nature of the literacies needed for the twenty-first century, which involve more than reading texts or following a video tutor's example of how to execute a mathematical procedure; they also require teachers' and students' literate engagement with each others' mathematical thinking.

Background

Dynabook: Back to the Future

We draw inspiration from Alan Kay's 1972 concept for a tablet-shaped personal computer, which he called a *Dynabook* (see Kay & Goldberg, 1977). Although futuristic visions for the impact of computing stretch back much farther than Kay and have been updated many times since, we see Kay's concept as a distinctive turning point. In particular, it is at the heart of the possibilities now emerging for digital texts and applications in mathematics that seek to reinvent learning through interactive and manipulative media (see also Chap. 12 for contemporary types of networked mobile technologies).

Kay's vision may now be enabled by hardware and networked libraries of content. For example, his vision included a concept much like buying books on Amazon for a Kindle where one can connect to a library, peruse the information, choose an item to purchase, and take it home as a file on a personal tablet device. But Kay's core idea is not focused on what new hardware can do nor does it emphasize access to libraries of rich media content. Instead, it stresses the emergence of a specific class of relationships between the user and technology. Kay sees these relationships not through the metaphor of a "tool" but instead through the metaphor of a "medium" for thought. Quoting Kay (1998): "… we'll know if we have the first Dynabook if we can make the end-user experience one of 'reading and writing' about 'powerful ideas' in a dynamic form, and to do this in such a way that large percentages of the bell-curve can learn how to do this" (December 1998 section, para 3).

Visionaries before Kay had conceived of computation changing the experience of interacting with ideas. Bush (1945), for example, described readers' discovery of alternate perspectives on a topic of interest together with readers' creation of an annotated linkage between the perspectives ("trails") and a process of sharing those trails with other readers. Nelson (1992) took this notion further, envisioning the knowledge base not as "lumps" to be considered as wholes, but rather to be dissolved into their constituents, with the readers' task being to re-link the constituents into alternative narratives. Engelbart (1995) situated the readers' task as essentially collaborative and the computer's role as augmenting human capabilities.

Each of these prior visionaries, either implicitly or explicitly, imagined the reader as a member of the intellectual or scientific elite operating in professional settings. In contrast, Kay sought ways to engage children and adults from diverse walks of life in their everyday contexts (e.g., at home and in the park). He imagined his Dynabook as a very democratic medium. In the twentieth century, it was hard to imagine diverse throngs of people from all stations in life reading and writing in a computational medium. Today, mobile devices such as smartphones, e-book readers, and other types of tablet computers are part of our daily lives and social networking applications like Facebook, Twitter, and Wikipedia depend on everyday people to write and read their content.

Kay's vision, however, requires more than routine social networking because Kay also wanted people to more easily and frequently engage with powerful ideas. Like Seymour Papert (1993), Kay saw the dynamic, interactive capabilities of computational media as opening up new ways to playfully engage with significant ideas through activities like programming, interacting with visualizations, exploring mathematical models, and playing with simulations. Today's commonplace applications show the promise of these tools and social media but need additional layers of design, focus, and support to advance new literacies, especially in the context of teaching and learning.

The existing educational research confirms that these dynamic, interactive capabilities can democratize access to powerful ideas (diSessa, 2000). For example, visualizations of graphs and motion provided through the SimCalc approach can enable a wide variety of students to develop deeper understanding of rates and proportionality (Roschelle et al., 2010; also see Chap. 2, Exemplar 1: SimCalc). In addition, students engage in reading and writing activities that enhance interpretation of ideas when they interact with graphs to make motions, write stories about them, and then discuss these motion stories with their mathematics teacher. Thus, we believe that the vision of dynamic books on portable devices, which engage everyday people in social activities around big ideas of mathematics and science, is viable.

Challenges for Digital Texts

Despite the promise, many details of Kay's vision must be worked out for it to be fully realized in practice including (a) attending to diversity, (b) meeting the unique requirements of mathematics in a digital medium, (c) engaging students, (d) supporting teachers, and (e) being aware of the changing nature of literary. We discuss each of these five challenges for digital texts next.

Diversity

Classrooms are more diverse than ever due to demographic shifts and "mainstreaming" of special education students. Although the ethnic and racial composition of individual schools can vary greatly depending on location, the percentage of ethnic minority students in K-12 public schools increased from 22.2% in 1972 to 42.4% in 2005, and the percentage of children aged 5–17 years who speak a language other than English at home and who speak English with difficulty increased from 8.5% in 1979 to 20.0% in 2005 (U.S. Department of Education & National Center for Education Statistics, 2007). In addition, there exists great disparity across states and individual classrooms in socioeconomic status (SES); children from low SES households and communities develop academic skills more slowly compared to children from higher SES groups (American Psychological Association, 2011). Finally, recent legislation (e.g., No Child Left Behind and the Individuals with Disabilities Education Improvement Act) requires all students to have access to the general education curriculum and to be included in the same assessments (Van Garderen, Scheuermann, Jackson, & Hampton, 2009). It is worth noting that gifted and talented students are also served in the mainstream classroom even though this practice is not federally mandated.

To meet the increasingly diverse needs of students with learning differences in the general education classroom, special education services are being brought to the general education classroom. The lines between general and special education are blurred and teachers are being asked to collaborate to meet the needs of an extremely diverse group of learners. These collaborative efforts are based on the idea that each teacher has specific knowledge and expertise that address the instructional needs of the class (Van Garderen et al., 2009). However, collaboration in theory does not address the friction that exists in practice (Kloo & Zigmond, 2008; Rea & Connell, 2005). Philosophical differences in pedagogy and learning theory create tension in the design of instruction. This tension can be an obstacle to the design of effective instruction. However, it can also be the vehicle that brings together special and general education researchers to conceive and design innovative instructional tools and practices to meet the needs of *all* students (Kloo & Zigmond, 2008).

Mathematics

Mathematics provides perhaps the most important opportunity, challenge, and test of the potential for new resources and new literacies to co-emerge. On the one hand, mathematics is widely considered to be a critical yet difficult subject, which can only truly be mastered with sustained engagement (Kilpatrick, Swafford, & Findell, 2001). On the other hand, many students are unwilling or unable to maintain this necessary engagement. A societal compromise of diluting mathematics to a grab bag of isolated procedures and skills, which can be mastered without deep mathematical thinking, is a strategy unlikely to prepare students for challenges they will face in the twenty-first century. To learn mathematics more meaningfully, students need to build connections over time through a coherent learning progression with adequate support for the affective challenges of maintaining interest and engagement (Stein, 2008). Despite decades of investment in new curriculum, paper textbooks have not made substantial advances on these challenges. Can we do better with a digital curricular resource? We must determine ways in which digital curricular resources transform the perception of mathematics from an inert, rote, algorithmic discipline to feature the true nature of mathematics as a creative, playful, and imaginative discipline.

Engagement

Engagement with meaningful mathematical ideas depends on the kinds of tasks students are given (Schoenfeld, 1985), the tools and representations they are able to use (Sfard & McClain, 2002), and the supports available when they encounter difficulties—and of course, on the pedagogical competency of the teacher. Technology can play a key role in designing tasks that are new and intriguing, in creating tools and representations that are sensitive to individual differences, and in providing layered supports when students need assistance. Technology can also encourage and support good pedagogy.

Supporting Teachers

Teachers need support to work with new forms of curricular materials, such as digital books. For example, researchers increasingly focus on educative curricular materials for teachers (Davis & Krajcik, 2005; Remillard, 2000). Emerging technological advances combined with Schulman's (1987) work on pedagogical content knowledge (PCK) have led to the technological pedagogical and content knowledge (TPACK) framework (Mishra & Koehler, 2006). Teachers are often underprepared to anticipate and leverage the specific connections in the TPACK framework. For example, it is challenging for teachers to know how a new visualization for addition on a number line might help learners the most if the role of number lines in their current curriculum was adjusted (i.e., a technology to content relationship). Likewise, new technologies for exploring a science concept via simulation may only pay off if teachers adjust their pedagogy in such a way that classroom discussion of concepts is enriched. Thus, a further challenge for digital texts is to provide supports to teachers for adjusting their pedagogy and their approach to the content so as to best leverage the new technological affordances.

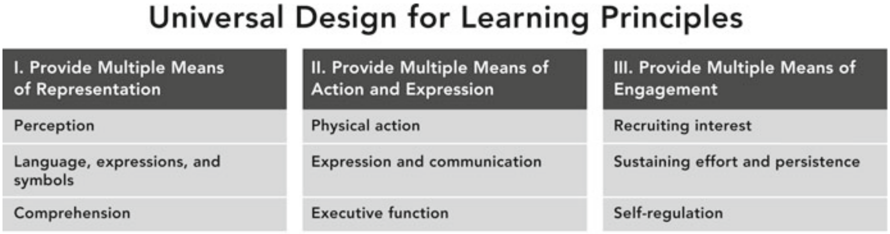
The Evolving Nature of Reading

A final challenge is that the activity of reading is itself changing as readers encounter a wider range of ways of gathering information and partaking of narratives. The text may now feature interactive representations, videos, and layered supports; it can exploit nonlinear navigation to feature connections among mathematical ideas and to better address the learners' needs; and it may provide paths through the same material but from different perspectives. In addition, reading may now be less about an individual learner silently decoding a long sequence of words and more about exploring the invariants of a virtual manipulative, or analyzing the thinking represented in an engaging video, or participating in a social activity with other readers engaged with the digital resource. Similarly, communication of information and ideas has moved beyond text-based writing to composing with audio, video, and images, as well as text (Brown & van Tryon, 2010; Gee, 2009; Leu, Kinzer, Coiro, & Cammack, 2004; Merchant, 2007; Mills, 2010). The goal in the design of new digital texts must be to cue a stronger, more active relationship between a reader and the text and to support the reader's development of skills and strategies for engaging productively with big ideas (Lankshear & Knobel, 2003; Lee & Spratley, 2006; Leu et al., 2004). In mathematics, especially but not exclusively, this active relationship may require a fundamental reading comprehension strategy that consists of writing and re-writing in other symbols, in other words, and in other pictures (Österholm, 2004, 2006).

Universal Design for Learning as a Framework

We believe the time is now ripe for a generic category of new digital books to arise, which we call *Dynabooks*, building on Kay's concept. However, the mere convergence of the tablet hardware, Web 2.0 software, and ubiquitous communications capabilities is insufficient to address the challenges we describe above. Thus, not every book in digital form can be a Dynabook. For example, Kindle e-Books, Apple's iBooks, Facebook, and Wikipedia draw from book models (the print book, the yearbook, and the encyclopedia, respectively) but none change how learners make sense of content. To more strongly advance, we need to go from using new media to reproduce print genres to designing Dynabooks that can leverage new media to support deeper and more extended engagement with challenging content. We suggest that an appropriate framework for designing such Dynabooks is *Universal Design for Learning* (UDL).

The core idea of UDL is to embed supports in the medium, which learners can optionally activate when they need assistance to continue their progress. The benefit of UDL is that it provides a research-based taxonomy of the kinds of supports that diverse learners may need and that technology can provide. The taxonomy is grounded in a vast literature on the brain, learning, and the role of technology and captures the dimensions of technological affordances that can extend learners' engagement with challenging content (see http://www.udlcenter.org/). According to the UDL framework, learners need supports for (a) connecting multiple representations of important ideas, (b) interacting with ideas and expressing ideas in new ways, and (c) maintaining a high level of engagement (Rose, Meyer, & Hitchcock, 2005; Rose & Meyer, 2006).



Universal Design for Learning Principles

I. Provide Multiple Means of Representation	II. Provide Multiple Means of Action and Expression	III. Provide Multiple Means of Engagement
Perception	Physical action	Recruiting interest
Language, expressions, and symbols	Expression and communication	Sustaining effort and persistence
Comprehension	Executive function	Self-regulation

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Fig. 3.1 Universal design for learning principles

For example, UDL suggests that providing multiple representations of a concept not only enables deeper engagement with that concept but also a broader range of learners to access the big idea. For the concept of *rate* in mathematics, exemplary representations include the slope in a graph, motion in a dynamic simulation, and the variable m in the symbolic function $f(x)=mx+b$. Looking at these in tandem can yield mutually supporting insights about how a rate coordinates two quantities, such as position and time. Likewise, students may be better able to express their emerging understanding of rate if they have opportunities not only to write and solve equations, but also to tell stories that feature rates and to build animations that feature rates. Finally, students may sustain their engagement with rate longer if they are exploring rate in the context of a challenge. For example, it can be more engaging to students to adjust the rate of a character moving at a constant speed so that a race between a constant speed character and a variable speed character ends in a tie than when teacher introduces "average rate" as a computation (e.g., divide the change in distance by the change in time, see Chap. 2 introduction for a specific example and Background for benefits to learning). Figure 3.1 outlines the three UDL principles for supporting diversity and engagement along with nine guidelines for designing curriculum based on each principle.

We see UDL as providing a framework that can guide the development of Dynabooks to enable a wide variety of learners to expand their literate engagement with powerful ideas. In this way, UDL addresses two of the five challenges we identified for digital texts: diversity (in its emphasis on multiple means) and engagement. In the next section, we present three exemplars of Dynabooks and discuss how each relates to the three UDL principles and addresses the challenges for digital texts.

Exemplars

Exemplar 1: Thinking Reader

Thinking Reader™ is an example of a series of digital books with content drawn from classic literature, which exemplifies the Dynabook concept. Based on research on digital learning environments and the UDL framework, *Thinking Reader* presents narrative texts that are commonly used in middle school curricula, such as *The Giver* by Lois Lowry. The *Thinking Reader* texts focus on *multiple means of action and expression* by providing upper elementary and middle school students with instruction and practice in using seven key reading strategies derived from the research-based reciprocal teaching paradigm developed by Palincsar and Brown (1984). In reciprocal teaching, students are periodically asked to stop and think about what they are reading using a specific strategy, such as summarizing what they are reading or predicting what will happen next. *Thinking Reader* includes supports for using the strategies, including tutorials and models of their use, which illustrates the guideline of offering options to enhance executive functions (i.e., last guideline for Principle II in Fig. 3.1). Different levels of support are available, enhancing student *engagement* and persistence (i.e., Second guideline for Principle II in Fig. 3.1). *Multiple means of representation* are provided through features, such as a multimedia glossary, that can be easily accessed from anywhere; students can click on key words in the text to view the glossary page for that word. Additionally, *Thinking Reader* provides access to text to speech with synchronized highlighting to aid fluency and support decoding, allowing students to focus their efforts on comprehension. These features illustrate the guideline that a variety of options be made available for language (i.e., written and spoken) when designing for multiple representations of big ideas (see Principle I in Fig. 3.1).

In *Thinking Reader*, prompts to use reading strategies are embedded at appropriate points throughout the text. As students enter a response to the prompt, teachers can view the responses and use them to inform their instruction. Through this process, teachers are also learning how to help their students employ these strategies with traditional texts. In this way, the UDL framework becomes a tool for teacher use as well as a tool for training the teacher how to differentiate instruction. Just by engaging with a *Thinking Reader* Dynabook, a teacher often improves his or her pedagogy by learning new techniques for differentiating instruction—techniques that can be carried over to other content areas as well. In this sense, the *Thinking Reader* addresses the challenge of supporting teachers in addition to student diversity and engagement.

In an experimental study, the Center for Applied Special Technology (CAST, a nonprofit research and development organization that works to expand learning opportunities for all individuals) evaluated *Thinking Reader* with 102 students who were performing below the 25 percentile in reading. Students in the *Thinking Reader* condition demonstrated significantly greater gains in comprehension than their peers in a traditional strategy instruction condition. Both students and teachers reported that they found the supports in *Thinking Reader* Dynabooks extremely helpful (Dalton, Pisha, Coyne, Eagleton, & Deysher, 2002).

We see *Thinking Reader* as a first step in reconstituting the relationship between the reader and the text, a relationship necessarily conditioned by and integral to the knowledge, skills, and competencies required for a reader to engage productively with the particular learning domain (narrative literature in the *Thinking Reader* case). The content within a Dynabook is presented in a way that reflects an explicit awareness of the strategies a successful reader will bring to it. Moreover, active engagement (writing, highlighting, and responding to strategic prompts in the case of *Thinking Reader* Dynabooks) in a Dynabook is cued as integral to the reading process. These writings become part of a cycle that draws the teacher into students' learning process. Thus, a Dynabook is not only something that a student reads but it also becomes a medium to foster interactions between the student and teacher.

Exemplar 2: Inquiry-Based Science Project

The application of the UDL framework to Dynabook design has been further explored through the Inquiry-based Science Project, funded by the National Science Foundation (NSF). The University of Michigan, the Education Development Center, Inc., and CAST collaborated on this project to create a web-based Inquiry Science System for UDL versions of science curricula. Two science Dynabooks have been developed using this system. The principle of *multiple means of representation* is applied to science content through a variety of media. Learner's interaction with a Dynabook is guided by the UDL principle of *multiple means of action and expression*. These Dynabooks further illustrate the changing relationship among the learner, the content, and the learning domain. For example, in the "Investigating and Questioning the World Through Science and Technology" curriculum, students are cued to (and strategically reminded of) two overarching activities to perform as they interact with the Dynabook: refine their own questions about the content and create and iteratively improve models of the phenomena under study. In both activities, there is not a single right answer. Instead, the Dynabooks seek to support the strategies that a successful learner will bring to science reading: questioning and modeling are as critical to science comprehension as summarizing and predicting are to narrative comprehension (i.e., to support executive function).

As they work with the Dynabook involving the above curriculum, students have access to "my questions" through a special tab. Students can repeatedly revise their answers and record their own questions about the content thereby personalizing the book to their own use and heightening their level of engagement (i.e., through recruitment of interest, see Fig. 3.1). Further, students have a special "my models" tab that records their successive attempts to articulate a model for the scientific phenomena under investigation. Students can also highlight the science text and compare their highlights with that of an expert, encouraging monitoring of their own study strategies. Students can describe their models verbally, through writing, or by drawing. In this way, this science Dynabook is also very much about *expression* of important science ideas, not only reading.

As is the case with *Thinking Reader*, the writings also serve as a medium to further student–teacher interaction. A central dashboard allows teachers to monitor students' progress through the book as well as review and comment on students' answers to questions as they go. Teachers can view an individual student's work or quickly see how all students in the class answered specific questions and modify instruction based on their understanding of the material.

Further, this science Dynabook is designed with an eye to its classroom use through a whiteboard feature. At a teacher's request, students can post any of their own writing in the Dynabook to a shared, public collection. The teacher can project this collection via a classroom display, and thus directly engage the students with the work they did in the book. Thus, the book is not only something to be read but also serves as a stimulus for student thinking, which can be written, shared, and publically displayed.

In these examples, we can see that UDL-inspired Dynabooks change the relationship of the reader and the text to be more dynamic thereby addressing the challenge of creating digital media that takes into account the evolving nature of reading. In addition, it provides the teacher with a means for organizing and planning, which enables learning to be more integrated with the social context of the classroom. Finally, a Dynabook provides an adaptive learning environment between teacher and student; the student learns content based on material presented by the teacher, and the teacher learns how the student is thinking about the concepts. This feature enables the teacher to present further instruction and questions that advance learning. In this way, the Dynabook supports the teachers' learning as much as it does students' learning.

Exemplar 3: Proportionality Dynabook

With the support of a recent NSF grant, the authors are further exploring and developing these ideas through a mathematics Dynabook intended for use by prospective middle school mathematics teachers (hereafter candidates or candidate teachers) and centered around the key middle school concept of proportionality. The difference between this exemplar and the previous two is that the Proportionality Dynabook content is being written from scratch to take specific advantage of the emerging medium for use with new teacher candidates, whereas the reading and science Dynabooks are based upon rendering preexisting paper-based texts in a UDL framework. Through research with mathematics teacher educators and special education experts, we determined the following three goals for the Proportionality Dynabook:

(a) Support and reward the candidates engaging more deeply in mathematical thinking themselves.
(b) Encourage candidates to draw connections among related concepts of proportionality.
(c) Develop candidates' awareness of potential student misconceptions and instructional options they could choose to support student development of more robust ideas about proportionality.

Achieving the student outcomes associated with the goals will require that students develop key strategies specific to mathematics just as was the case for reading literature (i.e., summarization and prediction) and learning from a science text (i.e., questioning and modeling). Two mathematics strategies we see as essential to accomplish the Proportionality Dynabook outcomes are exploring the same mathematics through multiple equivalent entry points and making connections among forms.

To support and cue these strategies the fundamental structure of the book is not a linear narrative but rather a 3×3 matrix that can be navigated in different pathways. The columns of the matrix are concepts in three related strands of middle school mathematics that develop students' proportional thinking: ratio (in the number strand), similarity (in the geometry strand), and linear function (in the algebra strand). Many middle school mathematics teachers do not recognize that these three concepts are deeply connected. For example, "slope" is the ratio of two sides (the height and the width) of a slope triangle, and the application of triangles to the slope relies on the concept of similarity. By presenting these three concepts side by side, the Proportionality Dynabook aims to encourage candidates to explore these sorts of connections.

The rows of the Proportionality Dynabook are organized by three different entry points for engaging candidates in the mathematics. Teachers can become familiar with the mathematics by exploring "challenging problems" designed to push and help them develop their own mathematical thinking. Candidates can further explore the mathematics by watching "video cases" of student thinking as students solve problems with ratio, similarity, and linear functions. Finally, candidates can also explore lessons that are specially designed to take advantage of the dynamic medium of the Proportionality Dynabook by presenting mathematical ideas in a visual and interactive format. For example, in the linearity section candidates develop the idea of linear function as they explore the relationship between timing of thunder and lightning reaching a campsite by interacting with an animation that is linked to data collection. The candidates first explore the phenomena more qualitatively, getting a feel for how the timing of the light and sound co-vary. Later, a table tool and a graph tool allow candidates to collect data from the simulation and plot it, exploring the pattern with increasing quantitative precision.

This sequence follows a common best practice in the use of technology to develop conceptual understanding, which is to move from informal to more formal analysis, while connecting related representations of a phenomenon. Overall, this rich matrix of related concepts and related ways to encounter the concepts in the Proportionality Dynabook takes unique advantage of the ability to construct a book that does not need to have a strictly linear ordering of pages. In addition, a concept of an expert tour is planned, which can overlay a step-by-step trajectory on the book when it is desirable to guide candidates through the book in a linear order.

Further, the Proportionality Dynabook is being designed to embed UDL features and thus give the candidates ideas about how to support engagement in challenging mathematics. For example, a glossary is available, which defines unfamiliar words and definitions, by using a mixture of pictures and words. Candidates can highlight words or sections in the Proportionality Dynabook and take notes in the margins. Further, when answering a question, candidates can write, draw a picture, explain verbally (into a microphone), or upload a file. In addition, "Stop and Think" prompts are strategically embedded in the text to encourage candidates to process the text more deeply.

Finally, the Proportionality Dynabook seeks to further develop the concept of the book as a social medium that enhances interaction between an instructor and his or her candidates. In particular, instructors can create assignments in the Proportionality Dynabook for their candidates. Assignments can ask candidates to respond to particular mathematical questions, to tour particular sections of the book (such as videos of student thinking), to highlight aspects of the text, or to make notes that freeform. Expressive use of all Dynabook features is simultaneously possible, and thus assignments provide structure but not limits to a users' emerging literacy. An instructor can track candidates' progress in completing the assignments. More importantly, the instructor can easily view candidates' work on the assignments and use this information to launch classroom conversations. For example, candidates can be asked to solve a mathematics problem and different solution strategies can be compared. Or candidates might be asked to highlight a portion of the page on similarity, which deeply reflects the related concept of ratio, and an instructor can compare what different candidates chose to highlight. In essence, the Proportionality Dynabook is designed to address all five challenges that digital media must meet in order for their potential to be fully realized in practice.

Next Steps

Research on Proportionality Dynabook

Specific next steps with Dynabooks could focus on action research in courses where researchers, teachers, and administrators examine the results of positioning these technologies in various curricular activity systems (see Chap. 2). We need to study Dynabooks in the context of emerging literacies to understand the potential for the medium and its literate use to co-evolve. Teachers and administrators could use the UDL framework to evaluate potential digital resources. For example, the proportionality Dynabook group is continuing to explore how Dynabooks are used in preservice teacher education. Influenced by Vygotsky's ideal that higher levels of mental functioning require social interaction, Silverman and Clay (2010) suggest that teacher candidates need social experiences where they can engage with mathematics in a way that encourages the development of deep, connected, unpacked mathematical understandings. Silverman and Clay suggest that the collaborative use of the technology serves to establish the social environment necessary to promote higher levels of thinking and the development of deeper broader understandings of mathematics and pedagogy. Likewise, Shreyar, Zolkower, and Perez (2010) propose that the text created through dialogue, written response, and diagram in a social environment, such as the classroom, can transcend the actual text in use. In this way, the original text serves as a vehicle for collectively making meaning of complex mathematical concepts, problems, and related pedagogy. An instructor in these models works to orchestrate the individual students in the class in such a way that, despite a beginning heterogeneous perception of mathematical concepts and pedagogy, the class ends up with a collective understanding of problems and approaches to solve them.

Throughout the field of teacher education, we plan to examine the following questions: How can Dynabooks prompt collective understanding in a classroom beyond what is possible with paper materials? What features of the Proportionality Dynabook are most engaging and capable of generating powerful ideas and novel perceptions of proportionality as integrating and connecting different strands of middle school mathematics? How can use of the Proportionality Dynabook help teachers become more aware of student thinking and multiple pathways for student learning? The answers we find will serve to influence our ongoing development of our Proportionality Dynabook and inform the field about emerging future Dynabooks.

Learning Sciences and Education

Most broadly, we see the field as poised to deliver a series of innovative Dynabooks and to use them to advance our understanding of three related issues. First, in order to better design and use emerging Dynabooks, we need expanded concepts of reading, writing, and literacy. Most textbooks are clearly not read in the same way that novels are, and there is little reason to merely expand old habits of using textbooks to the new possibilities afforded by the digital medium. Without a clear understanding of the "implied reader" (Weinberg & Wiesner, 2011)—the skill set of the reader/writer/user the Dynabook designer has in mind—it is hard to know how to design a Dynabook to maximize learning. Further, we believe it is important to broaden the notion to encompass a diversity of learners who may have differing skills, special needs, and engage in literate use of resources in various ways. As the field develops this understanding of implied readers, we expect that the concept of reading a Dynabook will be seen as less linear, more strategic, and more interactive (between a reader and the content as well as between individual and social modalities).

Second, we believe the field should focus on Dynabooks that extend and deepen students' and teachers' engagement with powerful ideas as distinct from "just in time" resources. We expect that just-in-time resources will proliferate and be highly useful to learners but that mathematics, in particular, will continue to be difficult to learn and require persistent engagement in a coherent learning progression, not just a string of disconnected supports from just-in-time resources. Our Proportionality Dynabook, for example, is designed to more deeply engage teacher candidates in thinking about the needs of their students, the nature of middle school mathematics, and the ways in which technology can be used to advance learning. We see UDL as a potential framework for guiding the design of Dynabooks that sustain students' engagement, offer them multiple opportunities for action and expression, and support deeper understanding through multiple representations. This framework could be fruitfully expanded to incorporate more detailed design principles and exemplars.

Third, we believe that the field could productively focus on how Dynabooks can be a much more supportive resource for teachers compared to existing textbooks. Today's paper textbooks are easy to use in a sense but not easy to use well. Recommendations for teacher professional development often focus on the needs to support continuous learning experiences over time. We see the potential for Dynabooks to become resources for teachers' ongoing learning and sharing with their peers. Of particular importance, we believe, is the possibility for Dynabooks to better connect the work of general and special education teachers by creating a common focus on the challenges that diverse students face in learning conceptually difficult material and the opportunities to adapt learning experiences to meet their needs.

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Chapter 4
Teaching Engineering Design with Digital Fabrication: Imagining, Creating, and Refining Ideas

Jennifer L. Chiu, Glen Bull, Robert Q. Berry III, and William R. Kjellstrom

An innovative and promising technology for enabling learners to visualize complex ideas and to demonstrate their understanding of these ideas in concrete yet sophisticated ways is digital fabrication. Digital fabrication is a process in which a digital design developed on a computer is used to produce a physical object through a computer-controlled manufacturing system. This type of system combines computer-aided design software that allows users to visualize solutions with manufacturing hardware to create objects. With the press of a button, the electronic designs materialize into physical objects through machines such as 3D printers, die cutters, laser cutters, and other computer-controlled machine tools (Gershenfeld, 2005).

Until recently, digital fabrication systems were too complex and too expensive for classroom use. Advances in technology make digital fabrication feasible in K-12 settings for the first time (Bull & Groves, 2009). Moreover, websites that enable educators and learners to share and modify designs can facilitate and enhance the use of digital fabrication in much the same way as they have for digital media. Digital media—sound, images, and video—underwent a transformation during the past decade through proliferation of sites, such as YouTube and Flickr. More than 48 h of video is uploaded to YouTube each minute of the day. This larger social phenomenon is reflected in educational adaptations through parallel sites, such as TeacherTube and SchoolTube, that enable teachers to create, share, and customize digital media. For instance, teachers who find or create a particularly useful digital resource can now post it so that other teachers can find the resource and customize it for their instruction of the same concept.

Digital fabrication extends this phenomenon to physical media. Sites, such as Thingiverse (www.thingiverse.com) and Shapeways (www.shapeways.com), allow consumers to share and replicate physical objects in the same manner as digital media. Educational counterparts of these repositories include the 3D Printables wiki

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J.L. Chiu (✉) • G. Bull • R.Q. Berry III • W.R. Kjellstrom
Curry School of Education, University of Virginia, Charlottesville, VA, USA
e-mail: jlchiu@virginia.edu; gbull@virginia.edu; rqb3e@virginia.edu; wrk6mt@virginia.edu

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(http://3dprintables.org) and the Kinematics Models for Design Digital Library (http://kmoddl.library.cornell.edu). Teachers and students can create their own physical objects and post the designs for others to download, customize the object to their particular use or context, and fabricate their own physical resource. The types of models that can be fabricated in this manner include mathematical models, molecular models, anatomical models, geographic and geological models, and kinematic models in physics. Digital fabrication enables teachers and students to share and build upon each other's ideas in both virtual and physical realms.

These capabilities depend upon the presence of affordable fabrication systems in schools. Currently, the cost of such systems ranges from $300 for a computer-controlled die cutter to a $1,000 for a 3D printer kit. These educational systems do not support the same resolution and range of materials as their commercial counterparts, but are based on similar underlying concepts. A stereolithic (.stl) file sent to a thousand-dollar educational 3D printer can as easily be transmitted to a $30,000 industrial fabricator or an online service bureau.

The current status of digital fabrication resembles the era during the transition from mainframe computing to microcomputing. Early microcomputers, such as the Altair, did not initially have the full computational capabilities of their larger mainframe cousins. However, they were accessible and affordable. This situation provided a need for consumer-oriented software, which supported the development of a programming community that ultimately created a much broader and diverse range of software applications than had previously been possible. Digital fabrication is at a similar stage of development today. Use in schools will require compelling curricular designs, which in turn will require educationally appropriate hardware and software. A consortium of non-profit educational associations is collaborating with both commercial and non-profit organizations to develop resources to support a community of early adopters. The Fab@School consortium includes universities (University of Virginia, Cornell), educational associations (Society for Information Technology and Teacher Education [SITE], Association of Mathematics Teacher Educators), and commercial firms (FableVision, Aspex).

This chapter considers educational applications of digital fabrication that are feasible today as well as more sophisticated educational uses that will become possible in the near future. In particular, this chapter explores how digital fabrication technologies can help students construct understanding of concepts and skills by creating, sharing, and refining designs and ideas.

Background

Constructing Understanding Through Engineering Design

Digital fabrication technologies fit naturally with learning by design frameworks that leverage constructivist and constructionist perspectives. *Constructivism* asserts that learning does not transmit from teachers to students through didactic methods, but that learners actively construct their understanding through interactions with peers, teachers, and their environment (Bransford, Brown, & Cocking, 2000). *Constructionism* argues that physically making an object or artifact augments learning and the construction of knowledge (Harel & Papert, 1991). Constructing personally relevant artifacts and objects builds upon the rich variety of ideas that students bring to class, encourages multiple representations of knowledge, and spurs students to share, add, refine, and restructure their ideas. For example, Papert (1980) employed computer-controlled robots known as "turtles" (due to their hemispherical shape) to facilitate mathematical thinking. Later the LEGO-Logo project provided children with the tools to create their own robotic turtles. Much research documents the success of these approaches in teaching complex mathematical reasoning and understanding to children of all ages (Kafai & Resnick, 1996).

Digital fabrication technologies align with projects that encourage learning by designing, and in particular, engineering design projects. Engineering design is an iterative and open-ended process that involves creating, evaluating, and refining solutions to problems with certain constraints and specifications (Dym, Agogino, Eris, Frey, & Leifer, 2005). Engineering design projects provide context and utility for students learning mathematics and science because projects typically focus on learning and applying concepts to meet a certain goal. For example, in the *Skyline* project middle school students design skyscrapers with specified surface area and volume constraints (Burghardt, 2011). This task requires students to learn about surface area and volume as well as scientific ideas, such as forces due to gravity, and apply that understanding to design a skyscraper.

From an educational perspective, engineering design projects have four advantages. First, they positively impact learning in formal and informal settings (Katehi, Pearson, & Feder, 2009). Programs, such as *Project Lead the Way* (PTLW; http://www.pltw.org), have been developed to support engineering education at the middle and high school level. *Learning by Design* units lead middle school students through design activities that spur scientific inquiry (Kolodner et al., 2003). *Engineering Is Elementary,* developed by Boston Museum of Science, provides resources at the K-5 level that have demonstrated effects on science learning (Lachapelle et al., 2011). These kinds of engineering curricula can help students to develop both conceptual and process understanding, and to refine alternative ideas (Sadler, Coyle, & Schwartz, 2000).

Second, engineering design projects align with standards-based content for science, technology, and mathematics. For instance, key mathematical practices in the Common Core Standards such as making sense of problems and persevering in solving them, the ability to reason quantitatively and contextualize numbers and symbols, critiquing the reasoning of others, and modeling with mathematics (National Governors Association, Council of Chief State School Officers, 2010) are central elements of engineering design projects. When students calculate surface area and volume for their skyscrapers, they focus on the meaning of quantities in addition to modeling with mathematics. Students also learn to appropriately review the reasoning of others when they critique their peers' designs.

Third, engineering design projects foster engineering habits of mind such as systems thinking, creativity, optimism, collaboration, communication, and attention to ethical considerations (Katehi et al., 2009), which overlap with twenty-first century learning and innovation skills such as creativity and innovation, critical thinking and problem solving, and communication and collaboration (Partnership for 21st Century Skills, 2009). Because of these strong ties to content and skills, many reports have recommended that engineering design be incorporated into K-12 school curricula (Katehi et al., 2009; National Academy of Engineering, 2010).

Combining digital fabrication with engineering design projects enables students to create virtual and physical models that make their thinking visible. Coordinating these models offers unique learning opportunities for students to build and distinguish their ideas (e.g., Ainsworth, 1999). Although virtual media have an overall benefit on learning (Hoffler & Leutner, 2007), research also indicates that students have an illusion of understanding with virtual material (Chiu & Linn, 2008), have difficulty attending to important aspects (Lowe, 2004), and struggle to make connections from the virtual to the physical world (Chiu, 2010). Digital fabrication can provide a tangible link from the virtual to the material world and enable students to reconcile gaps in understanding that may arise through purely virtual learning. For instance, students can design two sections of a skyscraper virtually using CAD software, print a 3D prototype, and then discover when they physically put the two pieces together that their surface area calculations were incorrect due to shared walls.

Similarly, a student can use a visualization that demonstrates how a speaker works, and then employ 2D fabrication to build his or her understanding of a speaker out of paper, magnets, and wires. The student may believe that the wires must be somehow connected to the cone since the sound comes out of the cone, and build a speaker following this understanding. When the speaker does not work, the student has to determine why it failed by troubleshooting the object and by examining his or her understanding. Thus, in designing and building physical objects based on specific constraints (e.g., sound must be produced), learners receive feedback on the utility and value of their ideas, which enables them to reflect on, analyze, and refine these ideas.

Finally, engineering projects using digital fabrication enable students to rapidly test their design ideas and models in the physical world. For example, a student can make cones at various sizes to test ideas about how cone size impacts sound. The learner can collect data exploring the relationship between cone size and the amplitude of the associated waveform presented in a computer-based representation, and make generalizations about cone size and loudness. Explorations can lead to questions about frequencies and sound quality, which spur investigations into periodic functions and their connections to the physical world. Thus, as learners construct and test new objects, they expand their insight and range of understanding.

Infrastructure Requirements for Using Digital Fabrication for Engineering Design in the Classroom

Digital fabrication systems for engineering design have great promise for fostering thoughts and processes expected in the twenty-first century and they can do so by

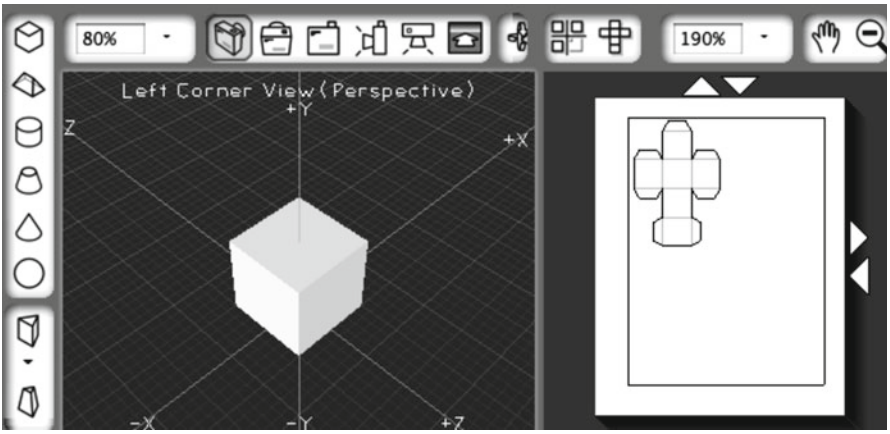

Fig. 4.1 2D fabricators print plane figures (nets) that can then be constructed into 3D shapes

avoiding some of the pitfalls associated with relying exclusively on virtual visualizations. However, classrooms need the proper infrastructure to take advantage of the next generation of 2D and 3D personal digital fabricators. A joint task force with representatives from the National Council of Teachers of Mathematics (NCTM), the International Technology and Engineering Educators Association (ITEEA), and SITE identified three key infrastructure elements that support the introduction of digital fabrication in K-12 classrooms, including: (a) digital fabrication hardware; (b) digital design software; and (c) exemplar curricula that incorporate engineering design principles. The first two elements are described next, while the third element is addressed extensively in the "Exemplar" section that follows.

Digital Fabrication Hardware for the Classroom

Two kinds of fabrication hardware are currently available: 2D and 3D. 2D fabrication uses computer-controlled die cutters to translate digital designs into nets, which flatten 3D figures into 2D plane figures (Fig. 4.1). These nets can then be reconstructed into 3D shapes. New 2D fabrication systems provide an effective entry point for digital fabrication in schools. These computer-controlled die cutters are similar to the mechanical die cutting systems traditionally used in schools, but employ computers to control the cutting head in place of mechanical dies. These 2D fabricators can be used to produce a variety of shapes and objects from materials, such as card stock and vinyl, and create perforated fold lines that help bend and fold designs into 3D shapes. These types of fabricated objects require construction to create complex or moving parts. These affordable fabricators can be purchased for as little as $300 and are about the size of an inkjet printer.

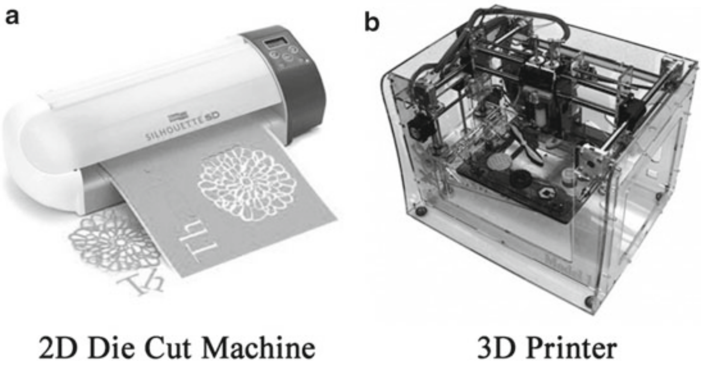

Fig. 4.2 Digital fabricators include (**a**) 2D personal computer-controlled die cutters and (**b**) 3D printers that extrude material through syringes to create 3D objects by deposition

3D digital fabrication translates digital designs directly to a 3D object. Two major approaches to 3D digital fabrication include subtractive and additive fabrication. Subtractive fabrication starts with a mass and removes material to create an object. Computer-controlled milling heads and laser cutters are examples of subtractive fabrication. Additive fabrication starts with nothing and successively adds material to create an object. A 3D printer accomplishes this by depositing one layer of material after another to form a three-dimensional object. 3D printing technologies have recently received considerable media attention for their potential to transform many domains (e.g., The Printed World, 2011). Educational versions of 3D printers are more complex and expensive than 2D fabricators, but are becoming more affordable. Emerging generations of personal fabrication systems available to hobbyists in kit form include fabrication systems, such as MakerBot (www.makerbot.com) and Cornell Fab@Home (www.fabathome.org). Educational versions of 3D printers build on these advances in personal fabrication systems. The Fab@School initiative, supported by the National Science Foundation, is developing an open-source 3D fabrication kit that will cost less than one thousand dollars in parts and that can be assembled in less than half a day. These relatively inexpensive, safe, and easily constructed fabricators can be constructed and maintained by students and teachers. Figure 4.2 displays both 2D and 3D printing machines.

Digital Design Software for the Classroom

Digital fabrication technologies require use of corresponding CAD software. In industry and colleges, engineers use CAD software, such as Solidworks or Autocad Inventor. These software packages are typically expensive and require intensive training to use. In schools, this software needs to be accessible, easy to use, and easily integrated into the existing curricula. There are a number of emerging CAD programs

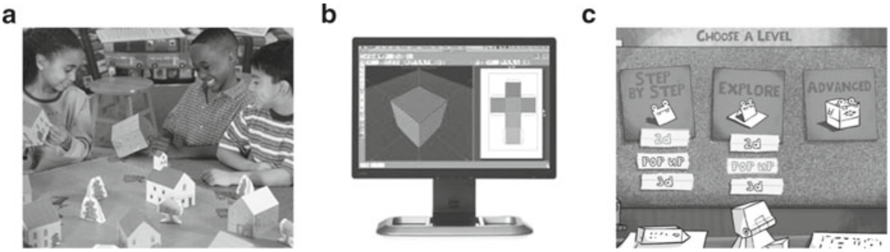

Fig. 4.3 Fabrication software suitable for school use include (**a**) Community Construction Kit (**b**) FabLab ModelMaker, and (**c**) Fab@School Designer

for younger students that are suited for use in schools (Fig. 4.3). For elementary school students, Community Construction Kit and Diorama Designer (Tom Synder Productions) allow students to design and construct 3D communities and dioramas from card stock. These applications include historically accurate design elements that allow students to design medieval, colonial, Native American, or contemporary buildings as well as their interiors. These programs were developed with connections to curricular objectives in mathematics and social studies for grades two through six. Fab@School Designer (FableVision) supports design of 2D shapes that can be folded into 3D objects. This application provides tools specifically for design of pop-up figures and note cards, and has been piloted in upper elementary classes learning science concepts, such as electricity, and mathematical concepts, such as ratio and proportion (Bull & Stearns, 2011).

In middle school, students have used FabLab ModelMaker (Aspex), an open-ended program that allows students to design 3D objects on the computer display. The application translates the object into a 2D net that can be printed and fabricated with a computer-controlled die cutter, such as the Silhouette. This program has been used successfully with upper elementary and middle school students learning mathematical concepts such as surface area, volume, and sequences and patterns (Burghardt, 2011). In high school, many students and teachers have used Google SketchUp to teach concepts across domains such as history, physics, and geology (for examples, visit http://sitescontent.google.com/google-sketchup-for-educators/Home/student-created-showcase). Google SketchUp enables students to create, share, and modify 3D models as well as export files to fabricators in much the same way as ModelMaker. Engineers and colleges use the commercial Google SketchUp Pro as an alternative to more expensive CAD programs for digital fabrication. Although high schools currently use Google SketchUp in their classes, limited information is available as to its use in conjunction with digital fabricators at this level.

This emerging generation of design software for students takes advantage of affordable digital fabrication hardware that is becoming available. It allows students to employ many of the same design techniques made possible by advanced CAD software, and makes digital fabrication feasible in K-12 classrooms.

Exemplars

Curricula That Incorporate Engineering Principles

Although there is little research directly testing the impact of engineering design projects with digital fabrication technologies to foster habits of mind or K-12 mathematics and science concepts, existing research is positive. We are at the forefront of exploring the potential of these pieces together with digital fabrication. At the undergraduate level, rapid prototyping machines help students engage in the practices of real engineers at various stages in their studies (Stamper & Decker, 2000). Maletsky and Hale (2003) explored the use of rapid prototyping in several college courses from first-year students to capstone design courses and found that students can focus more time on course material and less time on fabrication. Digital fabrication also helped instructors provide hands-on design experiences for their students.

Introduction of fabrication hardware into K-12 schools presents several considerations that include operation and maintenance, cost of consumables and supplies, and management of classroom logistics. Pilot sites in which these issues are being explored in elementary classroom and informal settings include the Center for Technological Literacy at Hofstra University and the Children's Engineering Group at the University of Virginia (UVa). Although these proof-of-concept studies do not have comparison groups, these studies demonstrate the potential of using engineering design and digital fabrication in K-12 settings.

Exemplar 1: Skyline Design at Hofstra University

The Hofstra Center for Technological Literacy has successfully integrated engineering design in K-12 schools. Elementary school teachers readily used projects that introduced informed engineering design (Koch & Burghardt, 2002). These engineering design activities enabled low performing fifth-grade students to become more mathematically proficient and resulted in a significant positive shift in student attitudes towards mathematics (Burghardt & Krowles, 2006). Follow-up studies report similar findings on the effectiveness of engineering design on improving student mathematical content knowledge and disposition towards mathematics (Akins & Burghardt, 2006; Burghardt & Hacker, 2008).

Researchers at Hofstra are currently integrating digital fabrication into their design projects for middle school mathematics students. For example, the *Skyline* project asks students to construct a skyscraper with specifications and constraints of shapes, volume, and surface area. The project guides students to learn about volume and surface area of various shapes as they construct 3D models of skyscrapers with digital fabrication. Students build an initial design, then use "knowledge skill builders" to learn concepts of surface area and volume and how it relates to their designs.

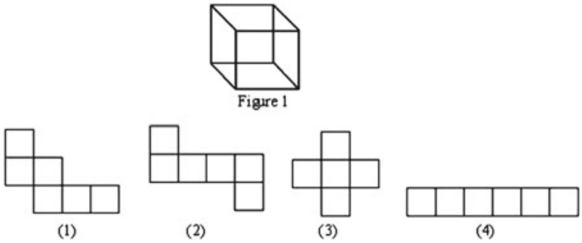

Fig. 4.4 Sample question from the Hofstra Skyline study

Thus, instruction of mathematical concepts is embedded within the context of the design activity. Students then use these concepts to revise their design given certain design criteria based on surface area and volume constraints. Initial results of student learning on standards-based assessment items that tested students' ability to translate 2D representations of 3D figures (Fig. 4.4) and to calculate the area of a circle and volume of a box were promising. Students significantly improved their performance from pretest (i.e., 18–59% of items were answered correctly) to posttest (70–97% of items were answered correctly), as well as their confidence regarding their mathematical abilities (Burghardt, 2011).

Exemplar 2: Elementary Classrooms with the University of Virginia

UVa piloted digital fabrication and engineering design in local third- through fifth-grade elementary school classrooms. These projects were co-developed with classroom teachers, and the learning experiences ranged from designing paper airplanes to building skateboard parks. In one project, students recreated famous architectural landmarks like the London Bridge during mathematical activities covering scale and proportional reasoning. Students participated in exercises involving measurement and architectural blueprints when studying surface area and volume, and negotiated 2D and 3D representations of objects through the construction and reconstruction of shape nets (Fig. 4.5).

The desire to create digital designs that transform into physical products generated student interest. Field observations, interviews, and focus groups with both students and teachers demonstrated insights into conceptual understanding and engagement. Annie, a fifth-grade student who participated in the paper airplane project, offered the following commentary on her experience designing airplane wings:

> [Designing airplane wings] is better than regular math because usually we do worksheets. You sit there and do this, this, and that. Instead of actually interacting with math. [For example, when we were first learning symmetry] we tried to find the line of symmetry within a square on a worksheet.

Fig. 4.5 Elementary school students negotiate 2D and 3D representations of objects during the digital fabrication design process

Annie went on to say that using the concept of symmetry mattered more when digitally designing and producing paper airplanes because asymmetrical wings cause irregular flight patterns. This insight resulted from her iterative approach that involved designing a wing, testing the wing on a paper fuselage, and then refining her design until she was successful. She not only applied the mathematical concept of symmetry to her wing, but also explored angles (wing camber) and geometric shapes (wing size). For Annie, the curricular connections and interest correlated more with the object that she created (e.g., paper airplane) than with the technology used to produce her physical model.

Preliminary results from assessments and observations revealed that the design activities provided teachers with information about student understanding of concepts. For example, two students who participated in the skateboard park project learned that decreasing the angle of the vertex in a miniature ramp ultimately increased the steepness of the hypotenuse in their 3D object. This realization occurred after close examination of their physical model. The students returned to their digital designs, made modifications, and reproduced a second ramp. To their surprise, decreasing the angle of the vertex resulted in a steeper ramp. After some discussion and teacher guidance, the students came to the conclusion that their internal belief that "the bigger the angle, the bigger the incline" was misguided. It is likely that the boys' alternative idea would have persisted had they remained in a digital setting and not produced a physical model.

The pilot studies also revealed insights into how to maximize the effectiveness of digital fabrication in classrooms. For example, with a limited number of fabrication systems, students waited in long lines before being able to digitally fabricate physical objects. Adaptations, such as grouping students with different design roles and design constraints on the size and complexity, addressed these issues.

Exemplar 3: Middle School Students Learning in Informal Settings

Researchers at UVa have also piloted digital fabrication and engineering design through workshops and activities in informal settings. These experiences offered outside regular school hours provide opportunities to explore a range of possibilities with digital fabrication. One is example is the Mathematics, Men, and Mission (M-Cubed) Program, a summer program designed to help rising fifth- through eighth-grade African-American boys develop strong mathematics, critical thinking, and problem-solving skills in order to develop a pipeline for entry into a specialized STEM academy at the high school level. The boys were selected for the program based on their potential for or current placement in advanced mathematics courses. All of the boys attended schools in the same school division in a southern state in which African-American students made up approximately 12% of the student population.

The M-Cubed program used digital fabrication to support an algebra- and geometry-intensive curriculum. For example, in one lesson the boys were presented with a task of designing and constructing packaging with the least amount of surface area for stacked cups. The activity required the boys to explore the algebraic relationship between the number of cups stacked and the height of the stacked cups. Additionally, they explored spatial reasoning to develop the connections of packaging that provided maximum number of stacked cups to the least amount of surface area. The Stacked Cups activity was one of several activities that connected digital fabrication with geometry and algebra.

Subsets of the boys were participants in a study that used primarily qualitative data sources. One finding from this work suggested that the boys differentiated between the unique qualities of mathematics and other disciplines by describing the challenge of tasks and their pride at persevering to completion. The comments of Jamal, a rising fifth grader, are representative:

> What I like about math is it’s kind of complicated, and I like, I want my work to be complicated so I can actually do better when I get to higher grades. And it feels like I finished something. It’s like when it’s hard, like when we were doing an engineering project, I feel like I finished something really good, like I did a really good job with it.

The boys’ descriptions included words like “complicated,” “complex,” “challenging,” and “requiring concentration.” The boys also described the distinctive ways problems engaged their thinking through problem-solving, interactive involvement utilizing multiple strategies, and connections to other disciplines. The unique layers of complexity and interconnections that the boys experienced contributed positively towards engagement with problem solving.

Summary

The three exemplars provide initial evidence that digital fabrication can be naturally motivating and interesting. Students from various backgrounds and settings automatically want to build and design their own artifacts. Although the software helps the students connect the 2D to 3D representations, students spontaneously discuss and negotiate how what they are designing in the CAD-like environments translate to constructed 3D artifacts as well as concepts learned in class. For example, in the M-Cubed workshop students made connections from the actual cups they were building and designing to the functions they created that expressed the height in terms of number of cups. By linking these representations and redesigning the cups to optimize stacking, students connected the physical object to the mathematical model or relationship.

Feedback from teachers in these pilot studies suggest that designing physical objects makes students' ideas explicit and tangible, which enables teachers to assess student understanding in different ways than traditional paper-and-pencil tests. For instance, the skateboard park project gave the teacher insight into the students' nuanced understanding of angles and inclines. Moreover, digital fabrication enables students to express concepts creatively and uniquely, which provides valuable insight for teachers on how students think and reason about concepts.

Next Steps

Key Issues for Digital Fabrication in Schools

The exemplars demonstrate that engineering design projects with digital fabrication can engage students in learning by design and provide an authentic, relevant, and effective context for learning science and mathematics concepts. Combining digital fabrication with engineering design can help students maximize the learning potential of design projects by testing, refining, and redesigning their solutions and ideas. Students can focus on skills such as creativity and innovation, critical thinking and problem solving, and communication and collaboration.

Although digital fabrication has demonstrated impact on industry, its impact on STEM education has yet to be fully realized. Future adoption will depend upon (a) parallel advances in engineering that may continue to make this emergent technology more affordable and accessible, (b) integration with existing school structures, and (c) proper support and training for teachers.

If digital fabrication technologies do indeed evolve with lower price points and are adopted by the public like regular printers, then this broader societal use is likely to be reflected in school use. Likewise, advances in software to support instruction, such as Google SketchUp, may make future generations of digital fabrication software more accessible to students and make broader integration into the curriculum more feasible. It is worth considering that the touch interface of tablet computers potentially provides a useful interface for computer-assisted design.

The success of engineering design with digital fabrication will require integrating the technology into existing school structures. Workflow, space constraints, and school resources must be addressed. Solutions such as putting students in design teams of three to four, having student groups work at their own pace, and having students take on certain roles assisted the pilot schools to orchestrate the fabrication process in classes. These pilot studies also demonstrate there is still much work to be done to figure out how best to integrate digital fabrication within different classroom contexts.

Effective integration of digital fabrication into schools will also place increased demands on teachers' technological pedagogical content knowledge (TPACK)—a form of knowledge required for effective use of technology with content and pedagogy (Mishra & Koehler, 2006). Teachers not only need to understand the technological innovation, but they also need to be able to make connections to existing curricular content and associated pedagogical strategies within their particular context. Pilot studies suggest that digital fabrication technologies can be incorporated into existing school curricula without requiring major transformation of teaching styles. Specifically, study teachers made connections and incorporated fabrication with concepts they were already teaching. For example, one pilot teacher integrated digital fabrication into an already planned skateboard park project.

Likewise, teachers' existing conceptual knowledge and beliefs about design impact the effectiveness of the activity. Some design activities may place too much emphasis on "gadgeteering" or trial-and-error problem solving, leave students without adequate conceptual understanding, and reinforce alternative ideas (Crismond, 2001). Teachers need support to balance emphasis on habits of mind and twenty-first century thinking skills, teaching of targeted concepts, as well as management of the activities themselves (e.g., Schnittka & Bell, 2011). Since engineering design ideally encourages integration of science and mathematics concepts, many teachers may be challenged to learn the pedagogical content knowledge of another subject. Elementary school teachers participating in the pilot studies described in the exemplars were accustomed to teaching both science and mathematics content. In contrast, secondary school mathematics teachers needed support to incorporate science concepts. Current research at UVa explores the kinds of support and professional development needed for these efforts to succeed.

Future Directions of Digital Fabrication in Schools

Digital fabrication seems to be particularly useful in contexts where students benefit from creating physical representations in both mathematics and science. Instead of learning from a 2D textbook page or 2D blackboard about geometric concepts in modeling situations, students can actually fabricate 3D solutions to geometric design problems. In addition to reading about levers and mechanical advantage, students can design levers that model the musculoskeletal system. Previously time-intensive design activities become more accessible to classrooms with digital fabrication. Although our exemplars have focused on mathematics and science content knowledge, digital fabrication can be used to help students visualize in other domains, such as language arts and social studies. For example, when students read about the Rosetta stone, they can manipulate a 3D replica.

Additionally, digital fabrication offers exciting potential to examine how students and teachers can build on the foundation of others' ideas with physical products. In the virtual realm, Scratch (http://scratch.mit.edu) is a program that enables users to create interactive media through a user-friendly programming environment (see Chap. 17 for more information on Scratch). Scratch has been very successful at building a culture of "remixing" projects; that is, taking underlying code and tweaking it to make a different videogame. With over 800,000 registered users and almost two million projects, a growing percentage of published projects are remixed (~30% in July 2011). Digital fabrication and similar sites for students and teachers to share designs (e.g., http://www.maketolearn.org) will make this kind of remixing possible in the physical realm.

However, remixing physical objects also introduces potential copyright and intellectual property issues. The non-profit Public Knowledge policy group views digital fabrication as the next disruptive technology, concluding that it will introduce issues even more complex than those resulting from the ability to digitally copy music and movies (Weinberg, 2010). Currently, regulatory restrictions have not been established. During this period, it is crucial to pilot as many uses of digital replication in educational settings to determine conditions under which digital fabrication is beneficial. These beneficial uses can help guide future regulation as well as educationally sound practice.

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Chapter 5
Professional Development Programs for Teaching with Visualizations

Libby Gerard, Ou Lydia Liu, Stephanie Corliss, Keisha Varma, Michele Spitulnik, and Marcia C. Linn

It is the last period of the day in the sixth grade classroom in Jefferson Middle School. Instead of daydreaming about the end-of-the-day bell or chatting with friends about lunchtime gossip, students are engrossed in exploration of the greenhouse effect.

Student 1: Okay, Go. Make it [albedo] really high?
Student 2: How about sunrays? Click on that.
Student 1: Want to put a cloud? What do you think is going to happen now when we put CO_2?
Student 2: [Reading text on computer] The CO_2 plus thinning air is going to help the clouds bounce off the sunrays. Do you see how they're going to do that?
Student 1: See! watch that one [sunray] right there.
Student 2: [Reading] Do you see how they're bouncing? The sunrays are bouncing off of the clouds. And they're bouncing off of the CO_2 too. So…

L. Gerard (✉) • M.C. Linn
Graduate School of Education, University of California at Berkeley, Berkeley, CA, USA
e-mail: libbygerard@berkeley.edu; mclinn@berkeley.edu

O.L. Liu
Educational Testing Service, Princeton, NJ, USA
e-mail: lydiaets@gmail.org

S. Corliss
Division of Instructional Innovation and Assessment, University of Texas at Austin, Austin, TX, USA
e-mail: stephcorliss@mac.com

K. Varma
College of Education and Human Development, University of Minnesota, Minneapolis, MN, USA
e-mail: keisha@umn.edu

M. Spitulnik
Contra Costa Jewish Day School, Lafayette, CA, USA
e-mail: MicheleSpitulnik@aol.com

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Student 1: Let's see how long it takes before [the sunray] leaves. Oh, that one's going….oh, no…that one's going back in [the earth].

Student 2: The CO_2 helped the clouds even though the CO_2 is bad. It reflected the sunlight.

Student 1: Because that's what, that's what's in the air right now on earth and… But, here [in the visualization], we can just like, magically take it away and we see what happens…

Students in the above example try out multiple conjectures about global climate change, a highly relevant science topic that is rarely taught due to its complexity. Students "magically" add and take away different variables like cloud cover and carbon dioxide and observe their role in earth's temperature. This interaction sharply contrasts with how students typically experience science in a secondary classroom. Most science instruction follows an absorption model of teaching and learning (Linn & Eylon, 2011). Teachers tend to focus on adding ideas through lectures, rather than on helping students refine their thinking by integrating these new ideas into their existing repertoire. Students work individually on drills and exercises that often fail to engage their curiosity and leave little room for them to articulate their understanding. Moreover, when classes reach up to 40 students, teachers find themselves limited to monitoring students' progress through end-of-unit tests. This situation makes it difficult for teachers to provide useful individualized feedback, and students become frustrated and disengaged as the only indication of success or failure they receive comes from a single test.

Inquiry activities featuring visualizations of science concepts move away from this absorption model of instruction. We define *visualizations* as computer-based, interactive models, simulations, animations, graphs, data tables, drawing, and diagramming tools. Visualizations give students the opportunity to direct their own learning as they explore the variables involved in complex science phenomena such as cell division, global climate change, chemical reactions, and evolution. However, scaffolding is necessary to assist students in using visualizations in ways that improve their scientific understanding. As shown in the example above, students often change the visualizations conditions rapidly—*make albedo really high…how about sunrays*, *click on that…want to put a cloud…what about* CO_2—and seemingly at random. Students are engaged, but they do not necessarily link evidence from the visualization to scientific ideas.

This limitation may in part be explained by research showing that visualizations can be "deceptively clear" (Chiu & Linn, 2012). That is, they can leave students with a feeling of deep understanding when in fact their understanding might only be superficial or erroneous. Although students can often point out salient features of visualizations, they need support as they (a) gather and use evidence from visualizations to formulate scientific explanations and arguments; (b) systematically experiment with a visualization by controlling variables and documenting outcomes; (c) sort out ideas gathered from different visualizations of related processes within the same scientific phenomena; (d) identify limitations of a visualization; (e) work effectively with a partner to reconcile visualization interpretations and articulate views; and (f) identify gaps in their understanding (Chiu, 2009; Dunbar, 1993; McElhaney & Linn, 2011; Zhang & Linn, 2011).

The Web-Based Inquiry Science Environment (WISE, http://wise4.berkeley.edu), which is the focus of this chapter, places visualizations in an inquiry-oriented learning environment that embeds scaffolding to enhance students' thinking about and with visualizations such that deep understanding does occur. Visualizations in WISE include but are not limited to interactive molecular level simulations; Flash and Java animations; graphs generated by students or data displays collected by sensors; data tables; diagramming, drawing, and animation tools; idea mangers; and video. In addition, WISE has embedded scaffolds and collects student data that teachers can easily use to provide feedback and reflect systematically on the effectiveness of their instruction. Schools are likely to have more success in supporting inquiry with WISE than with stand-alone visualization tools because of the visualization, inquiry scaffolds, and teacher assessment features embedded in WISE. Studies on professional development (PD) for stand-alone visualization tools have documented the substantial challenges teachers face when trying to design lessons that incorporate such tools to support inquiry and address science curriculum standards (Gerard, Varma, Corliss, & Linn, 2011).

In this chapter, we first describe the knowledge integration framework guiding the design of WISE. Next, we illustrate effective teaching practices with visualizations resulting from two PD programs that had positive results on students' science learning outcomes, though the programs differ substantially in how far-reaching their impact is and their overall cost. We end the chapter with recommendations for schools as they consider integrating visualizations into their science program.

Background

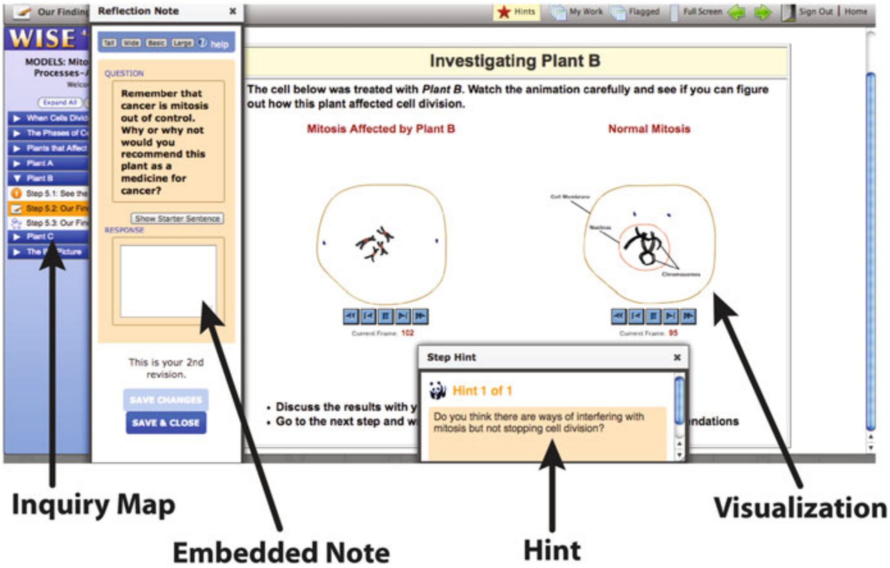
Knowledge Integration

We use the knowledge integration (KI) framework to guide the design of PD, curriculum, and assessments with respect to visualizations in WISE. This framework reflects a constructivist view that emphasizes building on learners' (teachers and students) repertoire of ideas, which are constructed based on their observations, experiences, and education. The framework is based on extensive research, which suggests that simply adding new ideas about teaching practices or the target science discipline is insufficient for inducing behavioral change (Akerson, Cullen, & Hanson, 2009; Henze, van Driel, & Verloop, 2008; Spillane, Reiser, & Reimer, 2002). Accordingly, adopting the KI perspective requires designing instruction such that (a) learners articulate their ideas about the target phenomena; (b) ideas are added to learners' repertoire in ways that make the new information accessible; (c) learners use evidence to sort out and distinguish among new ideas and their existing views; and (d) learners engage in an ongoing process of reflecting on and integrating the ideas, which most appropriately explain the science content, teaching, and/or learning phenomena (Linn & Eylon, 2011).

Web-Based Inquiry Science Environment

WISE is an exemplary web-based learning environment that embeds varied visualizations in inquiry activities to guide student investigation of a target phenomenon (Linn, Davis, & Bell, 2004). Each WISE project typically takes five to seven class periods (50 min each) to complete. WISE projects target topic areas that are aligned with state (CA) and national science standards, and that research suggests are difficult to teach because they are hard if not impossible to see in a school laboratory experiment or a regular textbook (Linn & Hsi, 2000). Extensive research demonstrates significantly greater knowledge integration on target science concepts when students use WISE than when they learn through traditional textbook instruction (Lee, Linn, Varma, & Liu, 2010; Linn, Lee, Tinker, Husic, & Chiu, 2006).

The WISE projects engage students in collaborative activities with visualizations such as investigating hypotheses, designing solutions to problems, critiquing scientific claims, and building scientific models. Assessments are embedded throughout the WISE projects to help monitor students' understanding and progress as they interact with visualizations. The embedded assessments ask students to make predictions about the visualizations, sort out evidence, and link ideas together to explain concepts and processes observed. The embedded assessment notes open in a pop-up window that students can place where they prefer on the screen (see Fig. 5.1) so that they can work with a note while they explore a visualization tool. Pop-up hints are also available on demand by clicking on the Panda icon (see top left of Fig. 5.1) and the resulting window can be placed anywhere on the screen.



Investigating Plant B

The cell below was treated with *Plant B*. Watch the animation carefully and see if you can figure out how this plant affected cell division.

QUESTION

Remember that cancer is mitosis out of control. Why or why not would you recommend this plant as a medicine for cancer?

RESPONSE

This is your 2nd revision.

- Discuss the results with y
- Go to the next step and w

Hint 1 of 1

Do you think there are ways of interfering with mitosis but not stopping cell division?

Fig. 5.1 A step in the WISE mitosis project

The assessments support students in monitoring their ideas to determine how new ideas relate to previous ideas, which facilitates KI. For example, in the *Mitosis* project, students investigate one big question throughout the project: how can plants help to stop cancer? The project *elicits ideas* about cell division by asking students to explain what cancer is to a friend and then predict what would happen to body parts if cells started dividing out of control. Students are supported to *add ideas* by viewing and manipulating dynamic visualizations of normal cell division and cell division when treated by three different plant medicines (see Fig. 5.1). The *Mitosis* project helps students *distinguish ideas* by guiding them to collect and use evidence from the visualizations. Students manipulate the visualizations to identify phases of mitosis in normal cell division and in cell division when treated by three different plant medicines. Finally, students *make connections among ideas* as they use the evidence from the visualizations of cell division to recommend one of the plants to a doctor as a medicine for cancer.

Exemplars

Approximately 200 teachers and over 40,000 students have partnered with the WISE research team over the last 5 years to refine curricular and instructional support for student learning with WISE visualizations. Teachers and their students participated in one of our two PD research programs focused on teaching with visualizations: Mentored and Online Development of Educational Leaders in Science (MODELS) or Technology-Enhanced Learning in Science (TELS).

The PD offered in each program differed with respect to the depth of interactions that the team or mentors had with teachers. MODELS focused on supporting teachers in two local school districts to integrate technology-enhanced inquiry science materials into their instruction. Each MODELS teacher participated in a 1-week summer institute for five consecutive years. TELS focused on scaling teacher use of the same technology-enhanced inquiry science materials. It supported over 175 teachers in seven states in implementing the materials in their classrooms. Teachers received support as needed in the classroom and participated in optional 1-day institutes.

Our two exemplars are based on data collected from seven teachers and their students who for 2 consecutive years: (a) participated in either the MODELS or TELS PD program, (b) implemented the WISE *Mitosis* and/or *Simple Inheritance* project, and (c) administered a student KI baseline test and delayed posttests. All teachers were similar in that they had at least 5 years of teaching experience in science, worked in schools with a diverse student body, and had multiple colleagues using the WISE curriculum in their school. In the next sections, we describe how a MODELS teacher and a TELS teacher improved their teaching practices with *Mitosis* visualizations over 2 years of PD. These two teachers were selected because they illustrate the changes we documented among the seven teachers within the TELS or MODELS PD programs. Then, we illustrate the comparative impacts of the PD programs on the seven teachers' teaching practices and students' science learning outcomes.

Exemplar 1: Teaching with Visualizations Through MODELS (Ms. Cramer)

Year 1

Ms. Cramer selected the WISE *Mitosis* project because her textbook-based lessons did not interest her seventh grade students nor did they help them realize the relevance of biology to real-world problems. Ms. Cramer was impressed with the relevant scientific issues addressed in *Mitosis* and the varied visualizations of cell division. Unfortunately, her first year implementing this project was challenging as technical and classroom management issues (i.e., registering students in the WISE environment, viewing student work in the grading tool, managing a classroom of students working in pairs on a computer, and troubleshooting a slow school Internet connection) reduced the amount of time she could focus on students' learning. However, the summer PD institute Ms. Cramer attended after her first year teaching with WISE provided her with extended time to reflect on her students' thinking in relation to the Mitosis visualizations.

In particular, Ms. Cramer and her seventh grade colleagues who also taught Mitosis focused on specific embedded notes that called for their students to use evidence from the visualizations to explain mitosis. The teachers reviewed their students' explanations, sorting responses according to how students linked their ideas using evidence. Ms. Cramer found that her students reported a wide range of normative and non-normative ideas about the relationship between cell division and cancer. Ms. Cramer and her colleagues refined KI rubrics to categorize and assess their students' ideas on these notes and planned whole-class discussions to prompt for deeper understanding. Ms. Cramer felt excited and well prepared to implement *Mitosis* in the upcoming school year.

Year 2

To provide readers with a sense of how the PD influenced Ms. Cramer's practice and students' learning with visualizations, we briefly describe her class sessions in the second year of implementing the *Mitosis* project. Ms. Cramer began the first session with a brief review of some key concepts and then guided her students to complete Activity 1, in which students are introduced to the role of mitosis and its relationship to cancer in the human body. Next, students began to distinguish the phases of mitosis and explore the possibility of using plants to cure cancer. Over the next 2 days, they analyzed interactive visualizations of cell division coupled with informational text and diagrams. Ms. Cramer guided students' thinking during this period through a whole-class discussion about strategies for experimenting with a visualization in which she explained the following:

> Let the model run through completely the first time but know that you're going to look at it again to see how you would divide the process into different phases…Then, run the model

> again, stopping and starting it to figure out what would be an important phase, what makes this part of the mitosis process different from another?

She also observed while students worked independently with the visualizations. For example, she noted that Anja and Paulo started and stopped the visualization at different points, that they recorded key characteristics of each mitosis phase in their WISE journal, and that they read about how professional scientists divided mitosis into phases and gave each a special name. Armed with this information at the start of the next class, the two students compared dynamic visualizations of mitosis occurring in three unique rainforest plants to the dynamic visualization of normal mitosis in a human cell. They gathered and evaluated evidence from the visualizations, and weighed the benefits against the potential side effects of the plants for treating cancer. They continued to add to and refine their argument concerning which plant would be the best treatment for cancer in their journal.

Ms. Cramer listened to the student discussions and observed that multiple pairs of students were challenged to relate the visualizations of abnormal mitosis to cancer treatment. She felt that this was an important time to review students' work. That night, Ms. Cramer read the student-pair responses to one note about the visualization of mitosis in Plant A, "What are your recommendations for Plant A as a possible medicine to treat cancer?" She found that students were challenged to sort out the evidence from the plant visualization to formulate a recommendation for cancer treatment.

> Students are really torn about whether they actually want to stop mitosis or not. With each of the plant models, they're like, "well, I don't want to choose any of these plants because if you stop mitosis you won't have any cells."

Ms. Cramer noticed a particularly interesting explanation written by Anja and Paulo, which utilized evidence from the visualization of Plant A and the description of the boy with cancer. With a tool in her Teacher Dashboard, Ms. Cramer flagged Anja and Paulo's response, along with a few other students' responses for comparison. In class the next day, she projected the flagged responses (clicking a button made each flagged example anonymous) and guided a lively whole-class discussion about *each model and weighing the different side effects of each plant treatment in relation to effects of cancer*. This discussion helped students to sort out their ideas about the relationships among the plant mitosis visualizations, effects on the human body, and tradeoffs of different cancer treatments.

In a culminating activity within the *Mitosis* project, Anja and Paulo participated in a structured online debate with their peers about the benefits and drawbacks of each plant as an effective cancer treatment. Ms. Cramer monitored the debate by circling the classroom to read what students were writing and to give suggestions as needed. She remarked to Paulo and Anja, *Tell your peers about all 3 plants. What did each one do? Why did you like/not like each one? Why did you pick that one?* Anja and Paulo revisited the visualizations of Plant A, B, and C and then substantiated their ideas with further evidence.

> We would recommend plant B because mitosis is stopped and the cell affected by cancer will simply just die without a nucleus and with its chromosomes floating around the cell,

> because during metaphase, when the spindle fibers were coming out, the plant caused the spindle fibers to retract…We recommended plant B instead of plant C because though they ended up with the same results, the cell affected by plant B never divided in the first place and was affected by the plant sooner. Plant A caused the chromosomes on the right side of the cell to disappear during anaphase making it so that the cell on the right will not be able to divide again. However, the cell on the left can continue dividing out of control, which is why we did not recommend this plant.

The principal who had stopped in to observe, read Anja and Paulo's response over their shoulders and was impressed by their use of evidence.

On the last day, Ms. Cramer led a class discussion on the current state of scientific inquiry into cancer treatment. She recognized that the mitosis visualizations illustrate not only how cancer treatments can work, but also the substantial limitations of cancer treatment. *I know several different kids who have somebody in their family struggling with cancer so I want them to finish the project with a bit of hope*. Some students who completed the project early presented research posters on the benefits and side effects of different treatments used today.

Summer Professional Development Institute

During the 1-week summer PD institute Ms. Cramer worked with her colleagues and the WISE researchers to analyze her students' responses to key assessments using the KI rubrics. She used her Teacher Dashboard to share the *Mitosis* project run with her other seventh grade colleagues so they could see her students' work in context. Based on their collaborative analysis of student data, Ms. Cramer and her colleagues negotiated customizations to the project and their teaching strategies in order to further scaffold students' use of the visualizations (see Table 5.1). They also refined their premade comment list for the *Mitosis* note regarding Plant A.

Exemplar 2: Teaching with Visualizations Through TELS (Ms. Lewis)

Year 1

Ms. Lewis decided to use the *Mitosis* project because she liked how it connected cell division to the issue of curing cancer. In preparation for the project, Ms. Lewis met with a TELS PD mentor who showed her how to register students in the WISE environment, manage student pairs, and assess student work. In implementing the project, Ms. Lewis found that the visualizations *really brought mitosis to life* [*and*] *made it concrete for the students*. However, she faced three challenges. First, technology issues arose as Ms. Lewis figured out how to locate students' forgotten WISE passwords, arrange students into pairs, and access students' work. A PD

Table 5.1 Sample teachers' customization plan for MITOSIS project

Evidence	Changes to the mitosis project	Changes to in-class teaching strategies
Students demonstrated misunderstanding as to what was expected when asked to give a name to phases shown in the model in act 2 step 5	Reword prompt along with some more specific directions. Instead of "give each phase a name" I will write, "click on the edit button and make up a name for each phase"	A whole-class discussion on the benefits of classifying portions of a dynamic process will be valuable prior to this step. Use of analogies might be helpful—i.e., why we classify people as babies, children, adolescents, and adults even though there is no way to say exactly when one "phase" changes to another
Students don't pay attention to the particular parts of the cell affected by the plant in the model in act 4 and 5	Reword the question to elicit more detail in the cell mitosis	Students will review the model projected. Together we will watch movement of the mitosis processes. Verbalize the process reinforcing/interjecting vocabulary
Students had trouble making multiple links and justifications of using certain plants for the control of cancer control. No growth in the #5 answers from Year 1 to 2	Insert a step prior to this with a pro and con for each of the plants. Concept mapper that allows students to state qualities of the plants. This may also help them to recognize the parts of the cells and be more specific	A class discussion including a chart where students list the qualities of each plant
Students are not naming the specific parts of the cells	Question should be more specific to name and describe the part of the cell affected by the plant during mitosis	Verbal discussion reviewing the model showing the plant effects on mitosis
Students understand that uncontrolled mitosis is the cancer but are not making the connections with jobs that the plants do	Ask the students to make the connections between the changes that occur in the cell and how the plant is affecting the mitosis process	Whole-class discussion. Student derived charts giving the pros and cons of each plant for stopping cancer

mentor came to the classroom several days during the project implementation to assist Ms. Lewis. Second, integrating the *Mitosis* project into her existing curriculum proved difficult. Ms. Lewis had implemented the project after teaching the textbook unit on cell division with the hope that the visualizations would provide greater detail than the text. Students found this sequence frustrating. As Ms. Lewis introduced the project, several students remarked, *Didn't we already do mitosis—why are we doing it again*!

Lastly, Ms. Lewis' biggest challenge was assessment. To prepare for this task, Ms. Lewis *went through the whole project as if* [*she*] *was a student and jotted down* *possible answers that students might put for each question*. She was eager to grade all of her students' work to ensure that they linked appropriate evidence from the mitosis visualizations to cancer treatment, but generating criteria to grade those responses to the embedded notes was particularly challenging. She suggested that the curriculum developers provide a key for teachers that would give the correct answer to each question and a range of sample student responses. In addition, Ms. Lewis found reading, grading, and commenting on every single student response exhausting. She decided to give most students a numerical score for each response, but wrote only two comments.

Year 2

Technical issues during the implementation of the *Mitosis* project in Year 2 were minimal as many of the issues were resolved during Year 1. In addition, Ms. Lewis addressed the integration problem by redesigning her curriculum to *do the Mitosis project in conjunction with a little bit of notes that they* [*students*] *read in the textbook and the related workbook pages*. This solution allowed students to explore dynamic visualizations of mitosis, discovering for themselves the characteristics of mitosis phases and their critical role in the human body. Ms. Lewis was still committed to assessing students' learning in an ongoing manner as in Year 1. However, she was more strategic in how she did so in the second implementation year to resolve the challenges she experienced in the first year. We illustrate how Ms. Lewis's changes in practice, both her integration of WISE in the curriculum and her modified assessment practices, influenced her teaching practice and her students' thinking. This is evidenced through a vignette documenting her interaction with her students Joseph and Sara.

Ms. Lewis observed Joseph and Sara's discussion as they watched a visualization illustrating the different rates of cells division in muscle, liver, nerve, and skin cells. Sara hypothesized that *Different kinds of cells divide at different rates because they need to be replenished at different speeds. For example, muscle cells divide more often than nerve cells because they are damaged more often*. Joseph linked the rates of cell division to what he and Sara read as the definition of cancer, a term for diseases in which abnormal cells divide without control. Joseph commented, *I think cancer cells would divide as fast as skin cells because they divide frequently and will be able to recover as quickly as other cells would*. Ms. Lewis decided to grade the students' responses that night to help them sort out their ideas about rates of cell division and cancerous cells. She used a more efficient approach to grading. *The biggest difference for me from last year is the grading. I used to grade by group and now I grade by step. I can go really fast. This helps me help the children more quickly*. She wrote to Joseph and Sara, *Healing of a cut actually begins in a few hours. Do you think cancer is that fast*?

When Joseph and Sara returned to class the next day they read Ms. Lewis' comment and eagerly moved ahead in the project to learn more about cancer and cell division.

They began to investigate the visualization of normal mitosis, starting and stopping the model to distinguish patterns between phases. *We stopped the model when the chromosomes started lining up in the middle of the cell with the spindle fibers attached.* While the students worked, Ms. Lewis sat at her desk and read students answers in the grading tool. *I can grade as they are doing it, you know I can look up their answer and I know right away if they understand it or not.* She called up a few student pairs to her desk when she saw that their responses were off-track. *I pull them up very frequently to talk one-on-one. I quiz them, asking them why did they say that?*

For the next 2 days, the class worked hard to compare the effects of Plants A, B, and C on cell division. Ms. Lewis noticed that some students were *confused about what to do with the visualization of the Plants A, B, and C. I could see there are a lot of incorrect answers to the question, like three or four pairs having trouble, so we stopped and discussed.* Ms. Lewis reminded students of what to look for in the visualizations of cell division: What cell structure is affected? How does this impact the whole mitosis process? *I found that if I get the same question it does not take long to get them back on track through a class discussion.*

Ms. Lewis decided to grade and send comments to the students after school since she had observed how challenging it was for them to analyze the mitosis process in the visualizations. The PD mentor stayed to help Ms. Lewis reflect on students' work. She read Joseph and Sara's response *We think that Arias chromagonia is a possible cure because even though it doesn't stop the cell from dividing, it stops the chromosomes from reaching the other cell.* Ms. Lewis and the mentor wrote back, *Go back to the model. What phase of mitosis did the plant effect? Why is this important for curing cancer?* During the grading process, Ms. Lewis told the mentor her continued difficulty with grading. *We are not all experts in these areas. I've taught life science a long time but this is difficult.*

Students returned to class the next day and read through Ms. Lewis' comments. Sara and Joseph went back and watched the visualization of Plant A and of normal mitosis carefully. They added to their response *The phase of mitosis that was affected by arias chromagonia was Anaphase.* The principal popped in to observe but Ms. Lewis *barely noticed* because she was *so engaged.* Ms. Lewis continued to monitor and observe students carefully. The PD mentor modeled how to circle the room, kneeling down to talk with student pairs at their computers as they engaged with the visualizations. Ms. Lewis remarked to the mentor:

> My interactions with my students are different when I am teaching a WISE unit than regular teaching. It is more like one-on-two. There are a lot of students I don't have to help so they can move ahead and work with the visualizations without my assistance. They feel good about themselves.

As students completed the project, Ms. Lewis was pleased. *I enjoyed doing Mitosis myself, the models helped me in supporting inquiry.* She *extended the project one week so students could go back and continue to redo their notes one time and come ask if they have questions.*

Professional Development Through Mentor

At the end of the project, Ms. Lewis sat down with the WISE PD mentor to reflect on her students' work. Together, they looked over students' pretest/posttest data and identified areas of difficulty. Ms. Lewis noted that students did well at identifying how the plants affected mitosis, but few linked this back to the overarching issue of how to use the plants to treat cancer. Ms. Lewis planned to restructure her whole-class discussions about the plant visualizations to help students use the evidence to describe cancer treatment.

Impacts of MODELS and TELS on Teaching and Student Learning with Visualizations

Ms. Cramer and Ms. Lewis illustrate the trajectory of teachers who participated in WISE-related PD for more than 2 years. Consistent with the data from the other five teachers in our longitudinal study, the seven teachers reported that the biggest change they made in their instruction to support student learning with visualizations from Year 1 to 2 related to assessment and whole-class discussions.

All the teachers reported that they examined students' responses to embedded assessments about the visualizations more frequently and/or more efficiently after receiving PD. As a result, the average number of comments teachers in MODELS and TELS gave to each student during a WISE project increased from Year 1 to 2 (i.e., from 6 to 10 and from 2 to 7, respectively). All teachers in Year 2 encouraged their students to revise their work in the WISE project after receiving comments. This often meant revisiting the visualization to gather specific pieces of evidence to further substantiate claims or to distinguish among normative and non-normative ideas (see Gerard, Spitulnik, & Linn, 2010 for further detail). Additional research by Sato (2011) reveals that specific comments, which build on students' ideas about a particular visualization (e.g., What happened to the spindle fibers in the visualization of Plant A?), were more likely to result in high-quality revisions than general comments (e.g., Revisit the visualization and add evidence to your claim).

However, the MODELS teachers felt better prepared to evaluate student work than the TELS teachers, having spent time in the summer institutes collaboratively analyzing and scoring students' responses to embedded notes. The extended time available for planning during this 1-week institute may also explain why MODELS teachers led more whole-class discussions during the week of implementation compared to TELS teachers. Despite this difference, teachers in both PD programs did modify discussions based on reflections made with colleagues or mentors concerning the first year implementation.

A common strategy that teachers employed in the second year was to lead a whole-class discussion or "Opener" at the start of class based on student responses on key embedded notes from the previous day to clarify and build on student ideas about a visualization. Projecting the visualization on the wall during the discussion

Table 5.2 Descriptive statistics, t-test, and effect sizes on test performance over time based on professional development program

	Baseline test			Year 1			Year 2						
Teacher	N	Mean	SD	N	Mean	SD	N	Mean	SD	$t_{b,1}$	$t_{b,2}$	$d_{b,1}$	$d_{b,2}$
MODELS													
Rachel	48	−0.06	0.21	48	0.08	0.21	48	0.15	0.24	3.27***	4.56***	0.54	0.74
Danielle	50	−0.07	0.20	65	0.18	0.38	50	0.38	0.42	4.55***	6.84***	0.62	1.02
Cathy	68	−0.09	0.24	68	0.10	0.32	88	0.33	0.48	3.92***	7.13***	0.52	0.82
Penny	78	−0.02	0.19	78	0.10	0.28	76	0.28	0.29	3.13***	7.57***	0.39	0.94
TELS													
Barbara	129	−0.08	0.24	186	0.06	0.39	198	0.13	0.37	3.85***	6.14***	0.32	0.51
Sarah	119	−0.09	0.41	169	−0.04	0.26	130	0.13	0.59	1.08	3.42***	0.12	0.33
Gary	133	−0.09	0.49	176	−0.07	0.33	169	0.02	0.29	0.41	2.31**	0.04	0.25

The numbers under "mean" are the mean ability estimates for students taught by each teacher (put onto a logit scale from −3 to 3). The higher the estimate, the more able the student is. $t_{b,1}$ stands for the t-test value between the baseline and Year 1 data. Similarly for $t_{b,2}$. d = effect size, calculated by dividing the mean difference between the baseline and post tests by pooled standard deviation. $d_{b,1}$ stands for the effect size of the difference between the baseline and Year 1 data. Similarly for $d_{b,2}$

Note: $^{***}p < 0.001$; $^{**}p < 0.005$

helped students to distinguish its key features or identify its limitations. Students were then able to review their individual comments from the teacher, revise their work, and continue the project. Some of our more recent work suggests that these whole-class discussions can enhance student learning. Openers about students' interpretations of WISE visualizations resulted in more robust student understanding of the visualizations and in more frequent revision of student explanations of these visualizations than students who did not have a class discussion. Specifically, class discussions that engaged students in each of the KI processes (i.e., elicit ideas, add ideas, distinguish ideas, and make connections among ideas) resulted in greater student learning than discussions in which the teacher presented information shown in a visualization (Zertuche, Gerard, & Linn, in press).

Teachers' improved strategies for teaching with visualizations had a significant effect on their students' understanding of complex scientific ideas. Table 5.2 illustrates that students in all participating teachers' classes made significant achievement gains from the baseline pretest to the Year 2 delayed posttest on targeted mitosis and genetics KI assessment items. However, students of MODELS teachers made more significant gains in the first and second years than those of TELS teachers. Figure 5.2 shows the magnitude of the performance differences based on Cohen's *d*. An effect size larger than 0.80 is considered large, 0.50–0.80 medium, 0.20–0.50 small (Cohen, 1988). The finding that effect sizes of MODELS teachers tended to be medium and high while those of TELS teachers tended to be small provides further support for the intensive PD MODELS program in teaching with visualizations.

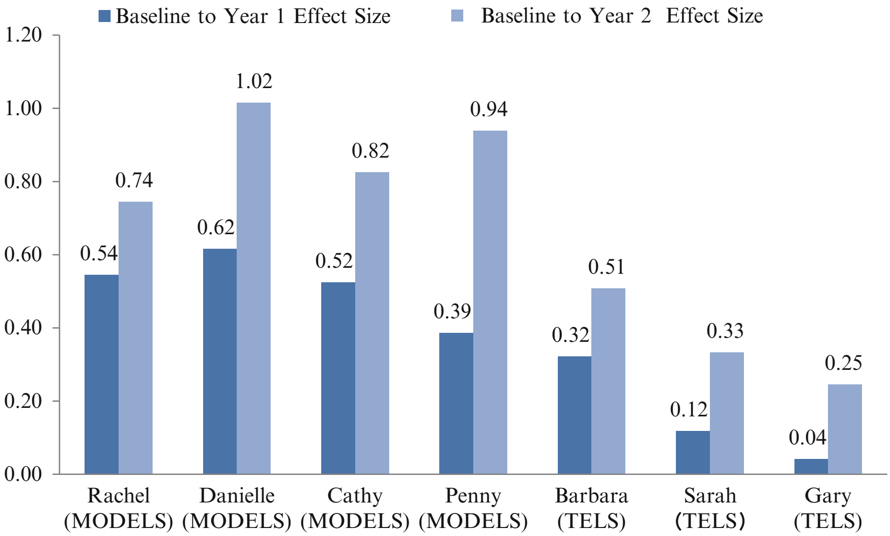


Fig. 5.2 Effect sizes of baseline to Year 1 and baseline to Year 2 performance for students taught by teachers in MODELS and TELS

Next Steps

Evaluating Visualization Technologies

The exemplars presented in this chapter highlight the key role PD and curricular materials play in teaching practices and students' learning of science with visualizations. Teachers provided essential guidance to help students make predictions about the science phenomena in the visualization, gather evidence from the visualization to distinguish among their many ideas about the phenomena, and integrate their ideas to explain scientific processes. This stands in contrast to many visualization tools available to educators today, which are stand-alone rather than embedded within curriculum projects involving scaffolding for inquiry, assessments, and intensive teacher PD. Stand-alone visualization tools are less likely to result in significant science learning as teachers have little, if any, guidance on how to effectively incorporate the visualization into inquiry activities aligned with standards. Without sustained PD, teachers have no time or access to curriculum design and domain experts to help teachers cultivate, test, and refine strategies for guiding student learning with visualizations (Gerard et al., 2011). In short, our research suggests that when purchasing technologies for a school(s), one should identify materials that embed visualizations into tested inquiry activities, provide assessment tools, and have extensive high-quality PD opportunities for teachers.

Developing Strategies for Teaching with Visualizations

The data from our WISE programs suggests that visualizations can significantly improve science teaching and learning when the PD, curriculum, and assessments are aligned with the KI framework. Alignment allows researchers to document the effects of PD on student learning. Further, it supports the notion of teaching as an evolving process in which practitioners become proficient by adjusting practice according to collaborative reflection on student work and instructional practices, not merely by repeating routines. The availability of the assessment data, detailing student learning in relation to instruction, is essential. Investing resources in intensive PD that supports teachers to analyze student work, reflect on teaching and assessment strategies, and collaborate with colleagues can improve students' learning outcomes faster, and most importantly, to a greater degree. The alternative and less costly option is to support teachers as needed in the classroom to navigate the technologies and reflect on student work as they implement new visualization tools in their classroom.

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Part II

Technologies that Support Learning by Collaboration

Chapter 6
Networked Technologies for Fostering Novel Forms of Student Interaction in High School Mathematics Classrooms

Tobin White

This chapter focuses on the novel forms of student learning and interaction supported by classroom device networks. In particular, my focus is on classrooms in which each student has a handheld calculator or computer connected to a local network such that the teacher can communicate with and orchestrate communications between student devices through a desktop computer. Handheld computing devices have been commonplace in secondary mathematics classrooms for some time; four-function and scientific calculators have gradually evolved to include graphing capabilities, dynamic geometry tools, and computer algebra systems. More recently, at least one commercially available system, TI-Navigator™, provides a means of connecting each student's graphing calculator to a classroom wireless network. At the same time, the current rapid proliferation of Smartphones and other mobile devices with networking capabilities suggests an increasing convergence between handheld computational tools and classroom connectivity that could significantly change the nature of mathematics instruction in the near future.

Over the last decade, several innovative research projects have begun to map out a range of novel activity structures and promising instructional possibilities presented by these networked classroom devices (DiGiano et al., 2003; Hegedus & Kaput, 2004; Roschelle & Pea, 2002; Stroup, Ares, & Hurford, 2005; Tatar, Roschelle, Vahey, & Penuel, 2003; White, 2006; Wilensky & Stroup, 1999b). Classroom network tools offer new possibilities for classroom interaction; they present ways of rapidly distributing information, exchanging ideas, and constructing shared artifacts that can support a variety of engaging and mathematically rich activities that would be difficult or impossible to implement in conventional classrooms. Importantly, and in contrast to many web-based environments that likewise capitalize on the power of networked computing to create novel and meaningful

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T. White (✉)
School of Education, University of California at Davis, Davis, CA, USA
e-mail: tfwhite@ucdavis.edu

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learning experiences through virtual forms of interaction, classroom networks hybridize conventional offline classroom discourse and online transaction; they can augment rather than replace conventional learning environments and face-to-face communication. Below, I examine some novel classroom activities made possible by classroom device networks, and consider their potential for supporting the teaching and learning of mathematics.

Background

Classroom networks inherit from traditional instructional practice three basic structures for organizing learning activity, centered respectively on individual student work, small-group collaboration, and whole-class discussion (Kaput, 2000). Many early designs for classroom device networks emphasized the individual level, often aggregating contributions from each individual student to provide feedback to the instructor as in the case of classroom response systems (for reviews of relevant literature, see Fies & Marshall, 2006; Roschelle, Penuel, & Abrahamson, 2004). These uses of classroom networks can be powerful resources for formative assessment and student engagement, blending anonymity of contributions to public discussion with private accountability in student-teacher transactions (Davis, 2003).

My focus in this chapter, however, will be on technology and activity designs for classroom networks that emphasize novel forms of interaction between students as well as between students and teacher, particularly in whole-class and small-group pedagogical modes. Indeed, promoting student participation in classroom discourse has been a central theme in mathematics education research and in the reform of mathematics teaching practices over the last two decades (Ball, 1993; Lampert & Blunk, 1999; Yackel & Cobb, 1996). Often, instructional activity in this vein takes the form of teacher-facilitated whole-group conversations in which mathematical meanings, arguments, and standards of evidence are established collectively (e.g., Forman, Larreamendy-Joerns, Stein, & Brown, 1998; Staples, 2007). In other instances, students work in pairs or small groups on collaborative problem-solving tasks, and thus have opportunities to discuss ideas and strategies, negotiate and coordinate interpretations, and provide peer tutoring (e.g., Barron, 2000; Boaler & Staples, 2008; Leikin & Zaslavsky, 1997; Moschkovich, 1996).

Classroom networks may represent a powerful resource for enriching these forms of classroom interaction. Research studies focused on using classroom networks to support whole-class activity structures have found that these systems can support students' agency and participation in collective mathematical activity (Ares, Stroup, & Schademan, 2009), attention to and identification with dynamic mathematical representations (Hegedus & Penuel, 2008), and opportunities to draw on diverse cultural and linguistic resources for participating in classroom discourse (Ares, 2008). Likewise, investigations of networked handheld devices in small-group collaboration have found such designs to facilitate greater communication, coordination and negotiation among peers (Zurita & Nussbaum, 2004), and to expand and enrich avenues for active participation in joint problem-solving activity (White, 2006).

Perhaps the most compelling aspect of classroom networks involves the potential for interweaving these social and interactional aspects of participation in mathematics practices with the conceptual richness of multiple and dynamic mathematical representations available on student devices and in public displays. Hegedus and Moreno-Armella (2009) describe this intersection of the social and the conceptual in terms of integrated communication and representational infrastructures, wherein the means by which students' devices interact and exchange information via the network overlap with the computational links between algebraic symbols, graphical displays, and real-world situations to form novel modes for learners' expression of mathematical ideas. Stroup et al. (2005) likewise emphasize the ways teaching and learning in classroom networks are organized in terms of dialectical relations between social and mathematical structures. Echoing these perspectives, Roschelle, Patton, and Tatar (2007) argue that transformative classroom activities with networked handheld devices will involve linking social and cognitive aspects of learning, in particular by providing means for using symbolic tools in collaborative and collective mathematical inquiry practices. Below I illustrate approaches along these lines, presenting examples of activity designs that utilize classroom networks to organize group-level interactions around shared mathematical artifacts.

Exemplars

In this section, I describe three different interactive classroom activities supported by networked handheld devices, each drawn from research projects focused on investigating the potentials of these tools for supporting novel forms of teaching and learning mathematics. The first is illustrative of a broad class of activities oriented toward engaging all students in the classroom group in a shared focus on dynamic mathematical representations collectively constructed from contributions sent through each student's device. The second example involves linking the devices of smaller groups of students to facilitate collaborative problem solving. The third design merges these two approaches, using a classroom network to integrate and fluidly shift between small- and whole-group instructional activities.

Exemplar 1: Collective Activity in Classroom Networks

Whole-class activities in classroom networks typically revolve around the interplay between individual students' personal constructions of mathematical artifacts (e.g., an algebraic expression, a polynomial function, a segment of a motion graph, a coordinate location) on their respective devices and the aggregation of those artifacts in a public display projected to the front of the classroom from a teacher's desktop or laptop computer, which functions as a server for the classroom network. To illustrate the properties of these activities, I consider an example of what Stroup et al. (2005) label *generative* activities. They use this term in reference "to orchestrating classroom activity in ways that occasion productive and expressive engagement by participants, characterized by increased personal and collective agency" (p. 188).

One such generative activity, using a TI-Navigator™ graphing calculator network, involves inviting each student in a classroom group to invent and contribute a function equivalent to $f(x) = 4x$. Students use their calculators to enter functions that match the criteria: $f(x) = 2x + 2x$, $f(x) = 40x/10$, and so on. As they send these contributions to the server, the graph of each function appears in a single window in the public display—as overlays of a single line in cases where the functions are indeed equivalent or as multiple curves in cases where students submit non-equivalent functions. Thus, the representational link between student-inputted algebraic expression and calculator-generated graph blends with the communication infrastructure of the classroom network to build a pedagogically and mathematically rich collective construction. The visual display of individual student contributions in the public graphing window provides teachers with a ready means of assessing student responses and anonymously diagnosing errors. The appearance of the graph of $f(x) = 2x * 2x$, for example, occasions opportunities to discuss algebraic procedures as well as to compare families of functions. However, it also engenders rich opportunities for creative individual expression and for joint mathematical exploration. For example, as students seek novel and distinctive solutions to the task (e.g., $f(x) = -113x + 117x$; $f(x) = 4(\sin^2 x + \cos^2 x)(x)$), they broaden the space of equivalent functions collectively constructed by the classroom group.

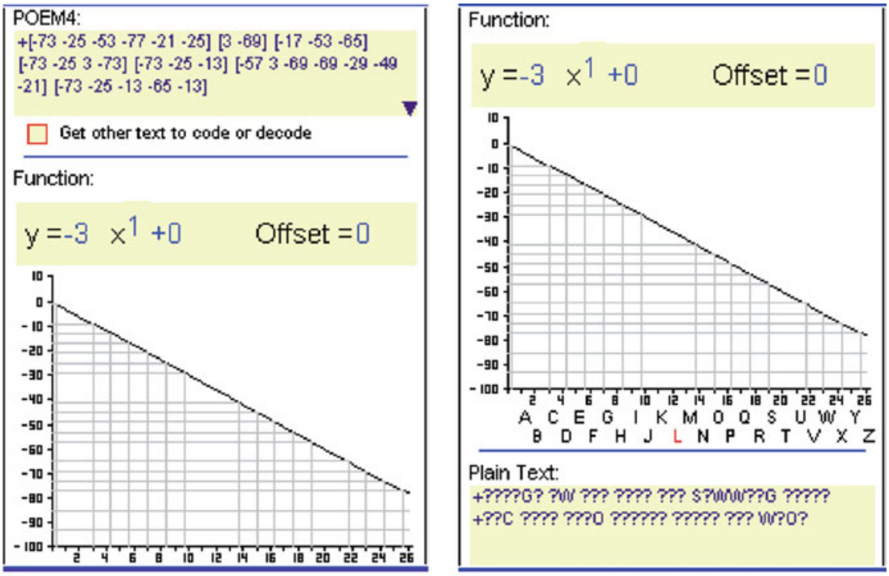
An important theme in the generative design work involves using the size and diversity of the classroom group as a resource for examining variation within families and other collections of mathematical objects (Stroup, Ares, Hurford, & Lesh, 2007). In effect, generative activities use the relatively large number of students—often 30 or more in high school mathematics classrooms—as a resource for ensuring that a range of ideas will emerge, leveraging that variety to draw out a corresponding diversity of mathematical forms. The power of the classroom network is in readily transforming that array of student productions into a dynamic set of mathematical representations in a public display. The aggregation of student-contributed functions in a single shared graph emphasizes and makes salient the underlying concepts of equivalence and the varied forms of algebraic expression. Instructional approaches to teaching Algebra I that incorporate generative activities using a TI-Navigator classroom network have been shown to improve student learning outcomes on a state standardized test (Stroup, Carmona, & Davis, 2005). In the next section, I explore the ways in which a design for small groups might likewise capitalize on fewer student participants working together to emphasize different mathematical relationships among correspondingly smaller sets of elements.

Exemplar 2: Collaborative Learning in Classroom Networks

To date, fewer classroom network designs have targeted small-group collaboration than the individual student and whole-class scales. This difference probably reflects aspects of both the hardware elements and the information architecture of commercially available classroom networking tools. Because these systems feature individual student devices and a whole-class server, but no small group-level physical platform or display, activities oriented toward individual students and the whole class are easier to orchestrate than the intermediary scale of small groups. Similarly, classroom network architectures are usually organized around exchanges of information from student devices to a teacher's server and the reverse, rather than between student devices. However, research using specialty applications designed to run on general-use mobile devices rather than graphing calculators designed for educational use has revealed some important insights and design elements for small-group collaboration that should be integrated into the next generation of classroom networking tools.

For example, a classroom application called *Code Breaker* (White, 2006; White & Pea, 2011) illustrates a means of using wirelessly networked handhelds to orchestrate small group collaborative mathematics by linking multiple representations with role assignments for each student in the group. The *Code Breaker* design is set in the context of cryptanalysis, and requires teams of four students to work together to try and decrypt a secret message. These messages are encrypted by mapping each letter in the standard alphabet to its ordinal value ($a=1$, $b=2$, …, $z=26$), and then by inputting those values into a polynomial function such that the output values form the letters of a ciphertext alphabet. When a team downloads a message that has been encrypted in this way to a handheld computer, each student in the group is assigned to examine the coded text using different representational tools included in the *Code Breaker* handheld software (Fig. 6.1) as the group works together to try to determine the unknown polynomial function used to encode the text.

Each of the different representational tools in the *Code Breaker* software are dynamically linked, so that entering a new polynomial function in the equation tool generates a new curve in a graphing tool, new sets of values in relevant table tools, and new message displays in a plaintext tool. Moreover, the classroom network server links the handhelds of all the students in each small group such that these function states match across all four computers. Thus, changes to a function displayed in one student's equation tool automatically propagate to all representational tools on all four devices. These features allow the simultaneous examination of several code and function representations, but require multiple group members to work together in order to coordinate these views and interpret them in relation to the problem-solving task. The activity design thus takes the form of a multiple representations jigsaw (Aronson, 1978; Cleaves, 2008); each group member is assigned responsibility for viewing one or two representations, and these responsibilities rotate regularly, with the intent of each student developing facility with each representational tool and a deeper understanding of its distinctive affordances for decrypting the ciphertext. Here, then, the representational infrastructure of multiple linked function displays aligns with the communication infrastructure of wireless networking between student devices. The aim of this approach is to simultaneously capitalize on the affordances of multiple linked function representations, and of multiple mutually dependent students collaborating in an engaging and



POEM4:

+[-73 -25 -53 -77 -21 -25] [3 -69] [-17 -53 -65] [-73 -25 3 -73] [-73 -25 -13] [-57 3 -69 -69 -29 -49 -21] [-73 -25 -13 -65 -13]

☐ Get other text to code or decode

Function:

$y = -3 \; x^{1} + 0$ Offset = 0

Student 1: Publisher

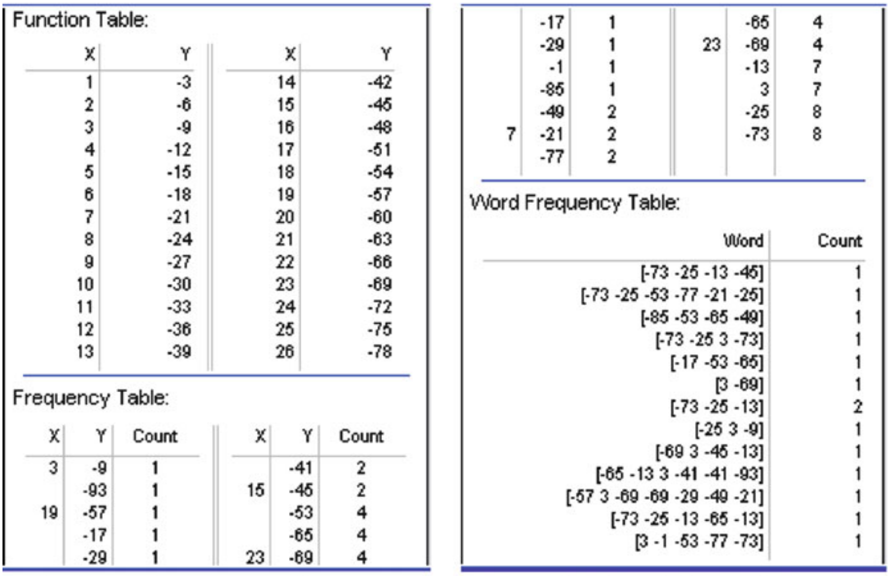
Function:

$y = -3 \; x^{1} + 0$ Offset = 0

Plain Text:

+????G? ?W ??? ???? ??? S?WW??G ?????
+??C ???? ???O ?????? ????? ??? W?O?

Student 2: Presenter



Function Table:

X	Y	X	Y
1	-3	14	-42
2	-6	15	-45
3	-9	16	-48
4	-12	17	-51
5	-15	18	-54
6	-18	19	-57
7	-21	20	-60
8	-24	21	-63
9	-27	22	-66
10	-30	23	-69
11	-33	24	-72
12	-36	25	-75
13	-39	26	-78

Frequency Table:

X	Y	Count	X	Y	Count
3	-9	1		-41	2
	-93	1	15	-45	2
19	-57	1		-53	4
	-17	1		-65	4
	-29	1	23	-69	4

Student 3: Equipment Manager

	-17	1		-65	4
	-29	1	23	-69	4
	-1	1		-13	7
	-85	1		3	7
	-49	2		-25	8
7	-21	2		-73	8
	-77	2			

Word Frequency Table:

Word	Count
[-73 -25 -13 -45]	1
[-73 -25 -53 -77 -21 -25]	1
[-85 -53 -65 -49]	1
[-73 -25 3 -73]	1
[-17 -53 -65]	1
[3 -69]	1
[-73 -25 -13]	2
[-25 3 -9]	1
[-69 3 -45 -13]	1
[-65 -13 3 -41 -41 -93]	1
[-57 3 -69 -69 -29 -49 -21]	1
[-73 -25 -13 -65 -13]	1
[3 -1 -53 -77 -73]	1

Student 4: Recorder

Fig. 6.1 Code breaker roles and representational tools

applied problem-solving activity. Previous research on cooperative learning has stressed the importance of positive interdependence among group members in the achievement of a shared goal (Johnson & Johnson, 1989). The *Code Breaker* example seeks to establish this interdependence by using the classroom network to distribute different representational resources to the devices of each group member so that contributions from all students are necessary to accomplish the objective.

As in generative design, the *Code Breaker* approach uses the mapping between student participants in a classroom group and mathematical objects in a shared virtual space to make important mathematical relationships and properties of these objects salient. In the case of small groups, however, the design focus shifts from expansive and potentially infinite mathematical spaces, like a class of equivalent functions, to a small number of components of a single shared mathematical object—in this case, multiple linked representations of a common function—that can be matched with two to four students working together in a small group. This design for small-group collaboration with networked devices has been found to support student reasoning about function representations, especially when groups develop successively more sophisticated strategies for using the connections among their devices to solve increasingly challenging tasks (White, 2006, 2009; White & Pea, 2011). In both the whole and small-group activity structures, these network-based relationships among students are intended to serve as resources to support learners' efforts to jointly navigate the conceptual territory delineated by their corresponding mathematical relationships in the space of the network. In the next section, I present a final example of an approach to using classroom networks to blend the affordances of these small and whole group designs.

Exemplar 3: Linking Multiple Levels of Classroom Activity

Ultimately, the viability of classroom networks as effectively and widely used tools for teaching and learning school mathematics probably hinges on their potential to effectively span and enrich the full range of conventional pedagogical modes and activity structures. Indeed, another potentially powerful use of classroom networks involves integrating classroom activity structures across the different scales of individual, small group, and whole group. Mapping student participants to mathematical objects in the network creates a flexible set of collective artifacts that can be readily shifted across instructional modes. To that end, I briefly present a design for Algebra One classes that links an activity for small groups, along the lines of the *Code Breaker* approach, with a whole-class design that shares some properties of generative design.

In an activity called *Graphing in Groups* (White & Brady, 2010), which uses a TI-Navigator™ system in combination with the NetLogo modeling environment (Wilensky, 1999) (http://ccl.northwestern.edu/netlogo/) and the HubNet network tools (Wilensky & Stroup, 1999a) (http://ccl.northwestern.edu/netlogo/hubnet.html), each calculator displays a graphing window and allows the student to adjust the coordinates of a point graphed within that window using directional arrow keys in the calculator. The coordinate points inputted through the calculators of each student in a small group are displayed together in a single graphing window on the

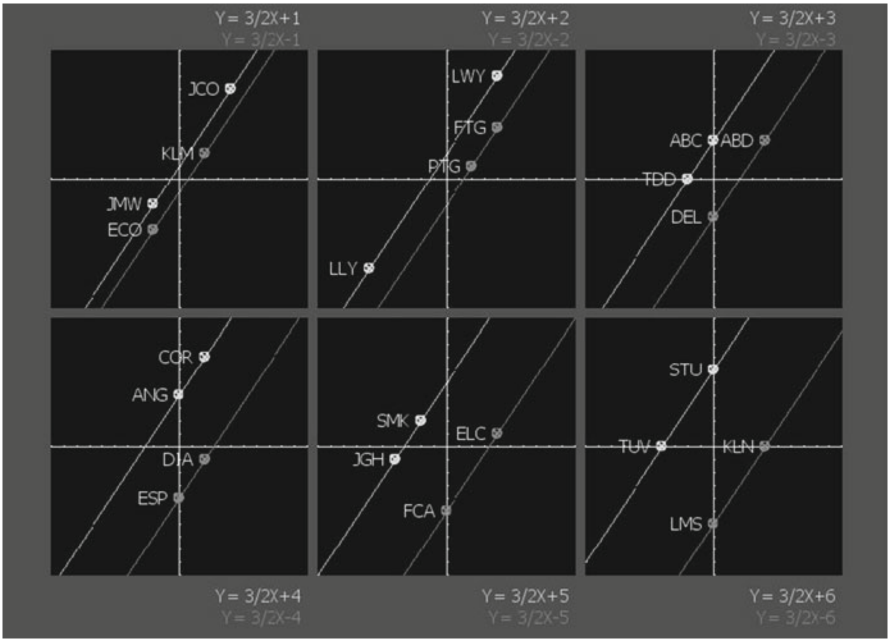


Fig. 6.2 Graphing in groups whole-class display of parallel lines activity

classroom server, creating a shared mathematical space for the members of a group. An array of these coordinate graphs, each of which is assigned to one or two student pairs, are all displayed in a grid on the server computer and projected to the front of the classroom (Fig. 6.2).

Like the *Code Breaker* design, *Graphing in Groups* uses the premise of assigning each student in a small group different elements of a shared mathematical object—in this case, two distinct coordinate points that jointly determine a linear graph—in order to foster collaborative investigation between partners. In the example of Fig. 6.2, 12 student pairs sitting together in the classroom were asked to position their points so as to construct lines with a common slope of 3/2. These pairs were also clustered into teams of four students, numbered groups 1 through 6, corresponding with the different windows in the shared display of Fig. 6.2 in which groups' respective graphs appeared (groups 1–3 formed the top row and groups 4–6 the bottom row). In addition to the assigned slope common to all pairs, one pair in each team was asked to make the *y*-intercept of their line equal to their group number, while the other pair had to make it equal to negative one times their group number. Tasks like these can layer two different kinds of collaborative activity in the interactive graphical environment: (a) between students in a pair as they negotiate ways of moving their respective points to form the desired line and (b) between pairs in a group as they discover or seek to maintain the parallel relationship between their respective lines.

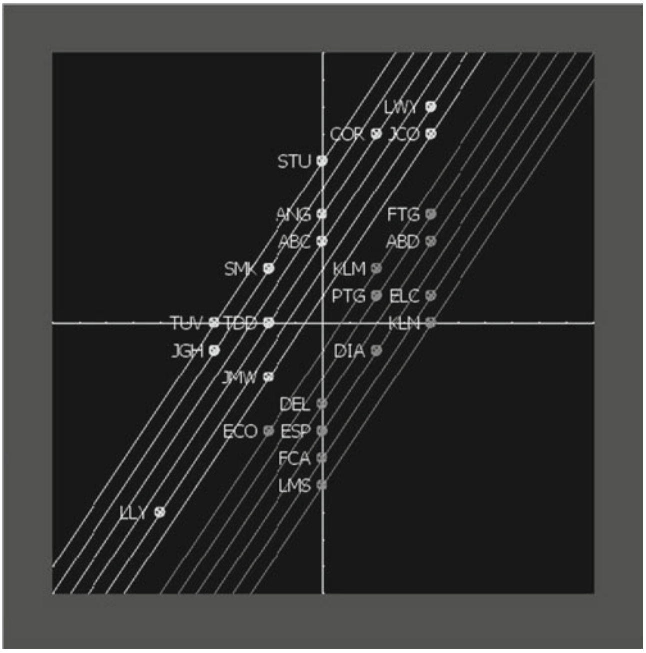


Fig. 6.3 Graphing in groups whole-class display of family of linear functions

But the artifacts the students produce as they work together in pairs and small groups also readily yield exploration of a broader set of mathematical relationships among these lines that can be readily made visible in the public display. The *Graphing in Groups* design includes a feature that allows the teacher to switch from a small- to a whole-group display, so that the student points and lines shown in each separate graphing window in Fig. 6.2 can be instantly redrawn in a single larger graphing window (Fig. 6.3). Switching from small- to whole-group scale in the display can mark a corresponding shift from pair and small group collaboration to whole-class discussion of the common and distinct properties of all their lines highlighted in this aggregate display. In this way, the activity seeks to capitalize on both small- and whole-group structures in order to illustrate corresponding mathematical relationships at each scale. Importantly, the activity sequence described here lacks the open-ended and creative qualities of a generative activity in Stroup et al. (2005) terms. I have chosen to present an activity in which the parameters of each student construction were well defined for clarity of illustration, and for which a particular result was anticipated in the whole-class construction. But the whole-group display in Fig. 6.3 remains dynamic; students can be invited to further explore the space of this family of functions, generating other lines with the same slope, or forming lines with the same intercept but different slope, or forming the same line using different points, or constructing perpendicular relations between the lines of two pairs, and so on. Designing learning activities in mathematics inevitably involves navigating some tensions between open-ended exploration and narrowly defined construction. My point here is not to emphasize either side of this balance, but rather to illustrate the flexible array of tools that classroom network tools provide for engaging students in each kind of task across multiple mathematically rich activity structures.

Conclusion and Next Steps

For technological innovations to support meaningful transformations in teaching and learning, they should be compatible with and seek to build bridges between both the daily instructional practices of teachers and the informal digital experiences of learners. Classroom networking systems offer a potential means of achieving that balance. For a generation of learners increasingly accustomed to personal and mobile computing devices, networking systems represent an engaging and mathematically rich means of connecting those informal digital experiences to classroom learning activities. Additionally, for teachers skilled in multiple instructional modes, they offer a means of tailoring technological resources to these varied pedagogical strategies.

The examples presented in this chapter primarily feature handheld devices that are widely used in high school mathematics classrooms and classroom-specific networking systems that are already commercially available. A next generation of Smartphones and other handheld multimedia devices with powerful and flexible computational and networking tools, already increasingly commonplace at the time of this writing, will likely make new classroom network platforms available and a much wider array of learning activities possible in the near future (see Chap. 11 for applications of wireless network devices in content areas beyond mathematics). Though these technologies are likely to evolve rapidly, the small- and whole-group activity structures presented here should continue to serve as important exemplars for teachers and designers seeking to capitalize on classroom networks as resources for supporting students' interactions with one another and with important ideas in mathematics. Each of these instances highlights the importance and the potential value of technology features that facilitate exchanges among students as well as between students and teacher. In the case of generative activity design, peer interaction and class discussion are achieved through the use of a collective mathematical space (a graphing window featuring function contributions from all students) and a public screen display. In the *Code Breaker* example, grouping student devices within the classroom network likewise provides a means of establishing interdependence among peers and orchestrating students' engagement in joint work. Finally, the *Graphing in Groups* example illustrates an approach to leveraging both a collective classroom display and communication between student devices in order to integrate interactive classroom activities across multiple instructional modes. One or both of these features are and will likely remain critical resources to include in new classroom networking tools if they are to support a full range of teaching activities and approaches necessary for creating rich and varied mathematics learning opportunities for all students.

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Chapter 7
Supporting Collaborative Knowledge Construction with Web 2.0 Technologies

James D. Slotta and Hedieh Najafi

A new generation of Internet applications is engaging users more actively in the exchange and construction of content than ever before. The Internet has evolved from a "Web" where information could be sought within a vast network of pages into a collection of social applications where individuals contribute, aggregate, "tag," and exchange materials including messages, votes, and other social information. These applications, referred to collectively as *Web 2.0*, have transformed the role of the Internet in our daily lives. For example, messaging and social networks are now inextricably linked to local, national, and world politics.

Amidst increasing references to the "twenty-first century knowledge age," education has begun a transformation process as well, particularly in areas of student records, teacher supports, and portfolios for assessment. Yet changes to classroom instruction come slowly, as teachers are rightly hesitant to partake in holistic changes to their instruction. However, the general climate of available technologies, better Internet and student computer access, and increased informational fluency (of students and teachers) are fostering innovation. This is particularly true in the domain of online learning where a high level of activity combined with a lifting of traditional constraints (i.e., classrooms and time schedules) has fostered a climate of innovation and experimentation (see Chap. 11, sections "Background" and Exemplar," for a description of virtual schools that offer online learning programs and their impact on learning).

As educational researchers who seek to understand and improve learning and instruction, we are attracted to the functionality and underlying epistemological commitments of Web 2.0. Educational research does have a theoretical tradition of social and collaborative learning, although these approaches have been challenging to study in classrooms. Perhaps the new socially oriented technologies can facilitate such approaches, allowing greater progress for research. We recognize the promise

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J.D. Slotta (✉) • H. Najafi
Ontario Institute for Studies in Education (OISE),
University of Toronto, Toronto, Canada
e-mail: jslotta@gmail.com; hedieh.najafi@utoronto.ca

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of Web 2.0 for education, particularly in its capacity to support communities of learners (in the classroom or online) and to enable a central role for student-contributed content.

However, the integration of Web 2.0 technologies for instructional purposes presents major curriculum design challenges. In addition to issues of access, privacy, and security, we must consider how to re-organize our instruction around social, cooperative principles, including user-contributed content and emergent learning goals. It is not straightforward to design instruction where students learn collectively, responding to emergent properties of their community knowledge, although such features commonly occur within Web 2.0 communities (e.g., online gaming or fantasy sports). As a field, we require exemplars of coherent designs in order to inform our theoretical models of learning in such a community-oriented approach.

In this chapter, we introduce Web 2.0 technologies like wikis, online communities, and social tagging. We discuss their possible applications for learning and instruction in K-12 and higher education. We argue that clear pedagogical models are needed for the design of Web 2.0 curriculum (sometimes called Curriculum 2.0), which typically involves a pedagogical shift toward social and collaborative forms of learning. We review the theoretical tradition concerned with learning within knowledge communities and then present our own recent model, *Knowledge Community and Inquiry* (KCI). Next, we present two exemplars that illustrate such instructional design. The first employs a wiki to coordinate a recurring graduate seminar offered at a university, organized as a knowledge building community. The second is a high school climate change curriculum that implements the KCI model, supported by a Drupal content management system. These exemplars illustrate the role of a pedagogical model in guiding the design of curriculum that takes full advantage of Web 2.0 technologies and epistemological perspectives.

Background

Web 2.0 Technologies

Although the arrival of the Web is still a fairly recent memory, its transformation into a social phenomenon has occurred rapidly in recent years. Not long ago, the Web was understood primarily as a "place" for storing and finding Web Pages that were static in nature—uneditable by anyone besides their owner. Although this vintage functionality of Web pages, hyperlinks, and search engines is likely here to stay, a new kind of Web has emerged that is deeply social in nature.

Thanks to user log-ins, permissions, and data mining techniques, Web applications can now track and manage the contributions, preferences, and social connections of users, as well as a wide range of other metadata, adding a dynamic, social quality to its content. Flickr opened its doors in 2005 as a mostly empty container, and was soon filled with two billion user-contributed photographs. Many of these photos contain user-contributed "tags," allowing visitors to filter all tagged photos by categories such as topic, time, popularity, or geographical location. YouTube, built under the slogan "Broadcast Yourself," became the largest of all content communities, with more than three billion views per day. Facebook, with nearly a billion users, is currently the largest Web 2.0 application, and a valued part of daily life for more than half of all Internet users in the world. Social and semantic metadata (e.g., tags added by visitors, visitor identities, or patterns of use) can be "mined" or actively processed by software running on the Web server, allowing for dynamic or emergent properties that result from the overall collections or patterns of use. For example, YouTube can display links to the day's most popular videos and Facebook can aggregate the number of "likes" and "dislikes" various posts receive.

Another Web 2.0 phenomenon has centered on the production and aggregation of written or authored media. This is most commonly seen in the form of blogs, where individuals subscribe to, and often discuss, the written ideas of peers in what is now widely understood as a global blogging community (or blogosphere). Each blog entry is typically tagged, allowing it to be aggregated by countless other blogs (via re-posts) or drawn into collections, either by individuals in their blog readers or by macro-blogs that compile smaller blogs under a single topical heading. Many respected intellectual sources have grown within this new blog ecology, which itself has now become a vital dimension of social issues and political processes.

Wikipedia, which tells us that there are now more than 150 million public blogs, exemplifies another form of Web 2.0 content aggregator, where materials are contributed to and edited by multiple authors. A wiki is an editable Web site, where pages can be created, linked to, and collaboratively edited by anyone who is logged in with proper permissions. Formally launched in 2001, Wikipedia offered a publically editable encyclopedia that quickly grew to its present status as a contemporary, comprehensive, and authoritative resource. Millions of users contribute to the Wikipedia content and organization, largely because they recognize that their collective effort is achieving something of universal value. Wikis facilitate asynchronous collaborative writing (see Chap. 8, section "Exemplar 2: Wikis in Support of Collaboration and Reflection-on-Action" for other benefits) and are not well suited for simultaneous editing of pages. They track all edits made to all wiki pages in what is known as the "page history," making it possible for users to identify the author of each revision, and even to revert back to previous versions. Access to specific wiki pages can be restricted to include only specific individuals or groups, allowing for the management of content communities where members can edit some pages and view others.

Content management systems are a recent genre of software that expand upon the functionality of wikis, supporting the design and development of Web-based communities that include a variety of features beyond those offered by wikis. Complex designs for user groups can be specified (e.g., teachers, student group 1, student group 2) in terms of access and editing permissions. Further, a wide range of content types and functionalities can be defined, including written pages, images, videos, Web forms, tags and ratings, social networks, and any other form of content one could envision for a Web site. Joomla, Drupal, Django, and many other platforms have emerged as ready-to-use toolkits that allow developers to quickly make highly functional Web sites. One common type of Web site is the online community, where users create, edit, tag, and access different kinds of content and functionality, with the design details guided by the specific needs or activities of the targeted user community. Some systems, such as Moodle, have been advanced specifically for coordinating educational communities. Others, like Drupal, are more general platforms that can be used for a wider spectrum of applications (see Exemplar 2 in the next section).

While the emergence of Web 2.0 applications has transformed our experiences and expectations of the Internet, a corresponding bloom of computer technologies is transforming the ways in which we interact with computers, peers, and our surrounding environment. Most people are familiar with the real time text messaging provided within Web sites like Google made possible by powerful new Internet protocols, such as eXtensible Messaging and Presence Protocol (XMPP). XMPP underlies the development of many new forms of real-time connectivity between distributed individuals (e.g., Google Docs, which allows multiple simultaneous editors to a page) with exciting new applications on the horizon for learning and instruction.

The wide availability of Smartphones that have persistent Internet (i.e., 3G) connections and geographical positioning (e.g., GPS) has also enabled new kinds of interactions. For example, a phone can now notify its owner spontaneously (i.e., without being queried) about the proximity of a friend, or a well-rated restaurant, or any number of other forms of data (see Chap. 12, section "Status of the Research on Mobile Learning Effectiveness" for additional benefits). Interactive whiteboards (e.g., SMART Boards), multi-touch tablets, and tablet computers allow us to directly manipulate images, windows, and other objects on the screen *directly* without using a pointing device (i.e., a mouse). Further, tangible computer interfaces like the Nintendo Wii or Microsoft Kinect are transforming the very nature of human-computer interactions. When combined with the new social metaphors and applications of Web 2.0, these technologies suggest a wide space of pedagogical designs, leading to new forms of instructional content; new modes of interaction between students, peers, and instructors; and new ways of engaging with the world through technology-mediated environments (Slotta, 2010).

Teaching and Learning with Web 2.0 Technologies

Web 2.0 technologies open the doors to a wide range of pedagogical approaches for K-12, university classrooms, large lecture courses, and online learning. The expanded abilities to connect students with peers, support collaborative work, and aggregate contributions within content communities hold great promise for the design of materials, assessments, activities, and interactions. Yet, designing curriculum that deeply integrates such media is challenging, particularly if done comprehensively so that the entire course is organized according to the social and collaborative products or exchanges that characterize Web 2.0 philosophies and applications. If a teacher or university instructor wanted to integrate Web 2.0 materials or approaches into his or her course design, what principles or even examples could be consulted as a guide? What metrics or measures of success would inform evaluation and successive improvement? Thus, it becomes important to identify instructional design models that enable such integration.

A middle school history teacher might add a blogging activity to his course, where students assume the identity of an individual from a specific historical period and write one or more blog postings from the perspective of that individual. Alternatively, he could re-organize his entire course around social or cultural themes, with students maintaining historical identities throughout the semester, blogging, and exchanging with peers in a series of carefully designed activities. Another teacher might add a wiki to her course in a supplemental way, asking students to add examples to a course wiki and to use Wikipedia as a resource. Alternatively, she could re-organize her entire course around an initially empty wiki, with students responsible for generating major sections of the wiki, which ultimately drives the progress of the course. A comprehensive integration of Web 2.0 approaches requires a fundamental re-thinking of our role as instructors and of the nature of student activities, with an emphasis on user-contributed content, tagging, online discussions, and other forms of social knowledge construction. Most instructors are unfamiliar with such designs, and there are few available examples or design frameworks to guide their efforts.

We are researching a pedagogical model for collaborative and social forms of learning where Web 2.0 technologies support all activities, materials, and interactions. Our interest in this knowledge community approach is inspired by Brown and Campione's (1994) Fostering Communities of Learners (FCL) project as well as by the Knowledge Building (KB) approach of Scardamalia and Bereiter (1996). The overall body of research on knowledge communities has made relatively slow progress, partly because the knowledge community approach was quite intractable to researchers and teachers before the advent of Web 2.0 (Slotta & Najafi, 2010).

In the past few years, however, renewed attention has been given to these theoretical ideas because of improved technologies, as well as our increased experience and familiarity with Web 2.0 practices. A common observation is that twenty-first century society has become increasingly knowledge-oriented and that schools must now help students learn to identify and resolve multi-faceted and open-ended problems, think critically, and collaborate with peers (Drucker, 1986; Scardamalia & Bereiter, 2006). Educators are coming to understand the value of having students work collectively on a problem, building a shared knowledge base, or networking with peers according to specific interests. Below, we review some of the relevant research on the knowledge community approach and introduce our own pedagogical model.

Inquiry-Oriented Knowledge Communities

Research in the Learning Sciences has advanced an understanding of learning communities where students and teachers negotiate their learning goals, develop a shared knowledge base, and collectively advance their knowledge and understanding (Brown & Campione, 1994; Scardamalia & Bereiter, 2006). In an earlier review (Slotta & Najafi, 2010), we articulated four fundamental dimensions that are common to this knowledge community approach: (a) a collective epistemology where members understand learning in terms of the growth or progress of their knowledge community; (b) development of a shared knowledge base, resulting from community discourse and practices; (c) pedagogical and technological scaffolds that facilitate members' participation in the practices of the community; and (d) collaborative inquiry activities that guide students' active engagement in community discourse and practices with the aim of advancing the community's knowledge.

The idea of collective epistemology represents a shift in our interpretation of learning, from the traditional idea of student-centered learning (e.g., 25 individual learners in the classroom) to that of a collective endeavor, where students first understand themselves as members of a community that is together advancing their knowledge and understanding. Brown and Campione (1996) compared such learning to that of a scientific community, where individual members are aware that their efforts occur within a collective endeavor, and interpret their products in terms of scientific advancement. Scardamalia (2002) refers to a "decentralization of responsibility" within the classroom, with the teacher no longer serving as the sole authority for setting the instructional goals or determining the learning activities. Within a knowledge community, students are responsible for identifying their learning needs, planning how to address those needs, and monitoring their own progress.

In FCL (e.g., Brown & Campione, 1994), students are organized into a scientific community. Various collaborative groups are defined, each with distinct forms of expertise and responsibilities including structured and spontaneous cross-talk that occurs between groups. Students create a shared knowledge base, which they apply in the performance of some consequential task. In the KB approach (Scardamalia & Bereiter, 1991), students are engaged in adding ideas and building on their peers' ideas, supported by a scaffolding technology layer to help them recognize emerging themes, points of productive conflict, connections amongst big ideas, and productive avenues of further discourse.

Despite its theoretical stature, the knowledge community perspective has not achieved widespread popularity amongst researchers or practitioners. In part, the limited uptake by researchers is due to the high demand of time and human resources required for the design, implementation, and evaluation of any knowledge community curriculum. The few published studies of FCL-inspired approaches report major challenges regarding instructional design and implementation (Sherin, Mendez, & Louis, 2004). For K-12 teachers, there is a clear mismatch between the open-ended nature of a knowledge community approach and the established ecology of heavy content coverage, particularly in secondary science. In one of the few published accounts of KB in secondary science, the authors acknowledge making several compromises and still falling well short of implementing KB (van Aalst & Chan, 2007). Thus, despite the promise of the knowledge community perspective for informing instruction that emphasizes twenty-first century knowledge skills and Web 2.0 technologies, there are serious challenges to its meaningful application.

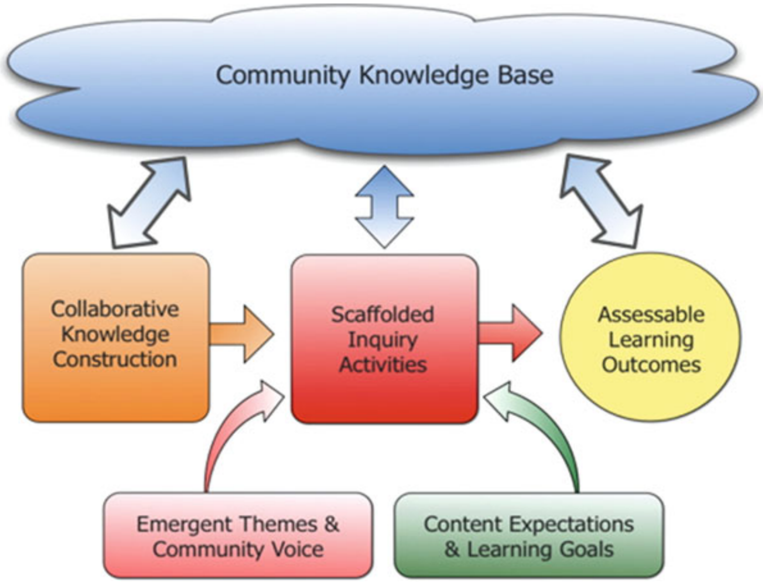


Fig. 7.1 Knowledge community and inquiry (KCI) model

Knowledge Community and Inquiry Model

In order to make the knowledge community approach more accessible (particularly for secondary science), we have developed a pedagogical model called KCI, which integrates the theoretical perspectives of knowledge communities and scaffolded inquiry (Slotta & Najafi, 2010; Slotta & Peters, 2008). The model guides our design of rich, multi-week curricula that begin with a collaborative knowledge construction phase where students explore a conceptual domain, articulate their own ideas, and create a collective knowledge base. Next, inquiry activities are defined that scaffold students in developing a deep understanding of targeted science topics, with the community knowledge base serving as a key resource (see Fig. 7.1).

The model is cast at a sufficiently high level of abstraction to allow flexibility for designs and application. It contains three basic principles: (a) that students work together as a community to produce a knowledge base; (b) that a sequence of collaborative inquiry activities draw upon the knowledge base as a resource; and (c) that the inquiry activities must address the basic themes that emerge within the community and result in assessable outcomes that are indexed to the learning goals. Our prior enactments of KCI have been primarily in secondary science, where the conceptual domain provides a clear framework for the structure of the knowledge base and the design of inquiry activities. For example, in a 12-week high school biodiversity unit, Peters and Slotta (2010) asked students to create a wiki of all 23 Canadian biomes. Students worked across five sections of the course to complete biome wiki pages, starting with carefully designed page templates that provided headers (e.g., flora, fauna, climate, environmental challenges), which served to parameterize the knowledge base. In a culminating inquiry project, students designed a remediation plan that addressed the ecological challenges of two or more Canadian biomes. The plan included required elements such as a discussion of the flora, fauna, and other aspects, as well as a description of its impact on Canadian biodiversity. Thus, we carefully designed specific activities and interactions (the pedagogical script) within the biodiversity curriculum based on a specific theoretical model that was supported by Web 2.0 technologies.

Central to the design of KCI curriculum is a *community knowledge base* that is created by students throughout the curriculum that they used as a resource within their inquiry projects. This knowledge base is populated with ideas or elements that are added to or improved upon by students during *collaborative knowledge construction* activities. For example, an empty wiki could be provided to students at the outset, with instructions that they must populate the wiki while also informing them that the wiki will be vital to subsequent activities. By carefully structuring the collaborative knowledge construction task, it is possible to engage students in a relatively open-ended way, while ensuring that the product of their efforts is sufficiently structured according to important domain variables. In turn, this allows the design of effective inquiry activities that will make use of the knowledge base (i.e., even in advance of knowing its specific contents).

Another important element within the model is that the specific *learning goals* should be addressed in the design of activities. This element allows curriculum designers to assess the learning outcomes in terms of the required local or governmental standards. Teachers must be confident that KCI achieves their science learning goals for it to be taken as more than a supplement to their instruction. Moreover, this requirement provides a helpful focus on the science standards as a reference in all of our designs.

All inquiry within KCI is either collaborative, where students work in small groups with clearly specified roles and goals, or collective, where all students in the class work in parallel (including some cross-talk) to address a broad inquiry topic. The inquiry activities in KCI must be designed in such a way that they engage students in using the knowledge base as a resource. Design projects, such as the "design a remediation plan" activity described above, provide a sufficiently open and engaging task while allowing some structure to be defined to ensure that the product of students' inquiry will address the learning goals. Thus, KCI blends the use of collaborative knowledge construction with scaffolded inquiry activities to ensure that students are engaged and that their efforts focus directly on the relevant science elements.

Web 2.0 technologies play an important role in the KCI curriculum, serving to coordinate activities, capturing student ideas, semantically aggregating materials, and guiding students to relevant resources (e.g., through the use of semantic tags). Scaffolding technologies such as reflection journals, Web data forms, prompts, or portfolio guides support students during activities. Ideally, such technologies will be integrated, allowing data to be accessible across activities and between software environments. Content management systems provide such coherent platforms, including most aspects of wiki functionality, as well as other basic (and many extended) Web features.

Designing such curriculum, even with a model like KCI, is nontrivial. It requires the conceptualization of a knowledge community, the specification of a knowledge base, and the indexing of all materials, activities, and outcomes according to that knowledge base. Further, it must address the learning goals with assessable evidence. Students must be engaged, and their collaboration must be consequential and not coerced. Even more challenging than designing such curriculum, however, is its enactment. A knowledge community approach requires the teacher to be fully engaged in every aspect of the curriculum, meaning that he or she must feel a strong sense of ownership. This is a process referred to as co-design (Penuel, Roschelle, & Shechtman, 2007), which has characterized all work concerned with the knowledge community approach (by ourselves and other researchers). Once a curriculum is designed and tested, it is conceivable that other teachers (i.e., who were not part of the design partnership) could adapt it for use in their own classrooms.

Exemplars

This chapter is concerned with the integration of Web 2.0 technologies into our instructional designs, recognizing the need for designs that include a social aspect of learning. In this section, we describe two of our own curriculum designs that have integrated Web 2.0 technologies to achieve a knowledge community approach.

Exemplar 1: Use of Wikis in Higher Education

Our first curriculum employed a wiki in support of an interdisciplinary university course called Knowledge Media and Learning. This course, facilitated each year by the first author, includes doctoral and masters students from education, information science, architecture, computer science, and sociology. The goal was to create a course where each year, a new cohort of students would build on the achievements of the previous year's students. Obviously, some form of persistent knowledge base for the course would be helpful for this purpose (although not sufficient in and of itself). We selected a pedagogical approach that allowed us to progress as a community and improve the knowledge base. We chose a wiki technology for our basic platform because it was open-ended, it was simple to use, and it would allow a persistent structure that could be revised as required. For the past 6 years, this course has provided a good vehicle for exploring and experiencing what it means to learn within a knowledge community.

The first time the course was offered, we began by brainstorming the kinds of knowledge media that would be relevant for learning and the knowledge communities where those media are commonly engaged. We articulated four major themes: (a) Content aggregation and semantic metadata (e.g., wikis, content management systems); (b) Immersive environments (e.g., Second Life, simulations, virtual worlds); (c) Geographical information systems (e.g., Google Earth); and (d) Augmented reality and ubiquitous computing (e.g., location sensitive iPhone apps).

These themes would be divided up among student teams (i.e., two students per team in the first year) who would be responsible for leading the class in an exploration of their theme and for maintaining that theme's wiki pages.

We created a single, overarching wiki page that linked to separate pages for each of the four themes. The students then added content, including links to readings and examples, summaries, and anything else they thought would help to capture their knowledge media theme. They also developed (in consultation with the instructor) one or more *collaborative knowledge construction activities* for their peers to do as homework, adding sub-pages to their wiki page, with headers to guide student contributions. For example, in the augmented reality theme, students added a homework assignment called "Our experiences with augmented reality" where everyone was instructed to use their mobile phone in some "locationally sensitive" manner, anywhere in the city, and then add a description to the Wiki. Thus, we employed the wiki not only to store and organize our ideas, but also to capture and make visible our experiences and insights. The pedagogical content of such designs was just as important, in terms of shared knowledge, as any specific links or examples.

In the second year, we formally launched the course, explaining to students that their wiki was being handed forward from the previous year and that they would be broadening and (hopefully) deepening in its content. We also introduced the emphasis on knowledge communities and collective epistemology, starting with a discussion of Scardamalia's (2002) paper that describes the teacher's role in a class where collective cognitive responsibility is maintained. The instructor explained that the goal was to learn more deeply about knowledge media by using them as a knowledge community. This meant that they needed to design a set of activities that engaged their classmates in actual experiences with their chosen theme, rather than just reading papers and discussing them. The wiki was a place where students would organize their efforts, give and receive homework instructions (which typically involved adding content to some wiki page), and aggregate their collective experiences.

To create such designs, students began meeting with the instructor as early as possible, often 3 or 4 weeks prior to their turn. We brainstormed possible approaches and shared responsibility for preparing materials, developing pedagogical designs, and creating accompanying wiki pages. When the day finally arrived for a theme team to begin, the leaders were well prepared and their classmates were eager to play along with any design since they had already experienced (or would be, in coming weeks) the challenge and thrill of engaging their peers in a such experiential learning. The design of such pedagogical content was one of the most challenging and important aspects of the course itself.

A culminating inquiry project was also added, where students used the knowledge base to develop a design idea for applying media themes to the needs of some in the knowledge community. A fifth theme was added for "social networks," and the names of two other themes were changed ("geographical information systems" became "layered information systems" and "augmented reality" was converted to "smart learning spaces"). As the ideas within the community matured, the wiki captured those ideas, making them accessible to future improvements. Figure 7.2

Abstract

ALTcity is a system that allows politicians, economists and policy makers, to use the actual urban environment as a survey instrument, probing for the public's support of civic programs and legislation by embedding questions about democracy into real space. The system poses alternative futures that isualize political movements or ideas like carbon taxing, different property tax structures, or alternative forms of health care, in situ, within the environments affected by them. These isualizations take place on mobile devices and at kiosks, through artist renderings of futures that could be. The public can use personal mobile devices to affect policy decision, as their aggregated hoices provide dynamic data which can be read and integrated into legislation by policy makers.

"Buckingham (2000) argues that young people's lack of interest in news and their disconnection from politics reflects their perception of disempowerment."By and large,young people are not defined by society as political subjects, let alone as political agents. Even in the areas of social life that affect and concern them to a much greater extent than adults; most notably education. Political debate is conducted almost entirely 'over their heads"(pp.218-219). We are moving away from a world in which some produce and many consume media, toward one in which everyone" - Jenkins, White Paper

User Profiles

There are two types of users: The Citizen and The Policy-maker. The Citizen is just that, a member of the public who has interest and who is implicated in civic issues. They are able to engage with kiosks and 'prompt' spots all around the city with mobile devices. They can answer questions, view alternative uses/futures for space based on policy decisions, and see visualizations of the outcomes of legislation overlaid onto the streets and parks they move through. They also have the ability to access civic discourse trends for topics that they care about. Their own decisions can be revisited with a 'time travel' tool that compares their choices to actual political outcomes. The Policy-maker is able to view data sets that emerge from kiosks and 'prompt' spots. They are also able to create visualizations that relate to new proposals, tying them to specific places where the public might find convenience or nconvenience from a set of effects tiggered by changes to law.

Project features:

Policy polls come from current city council issues
Push-pull bar interface
Colour coding for immediacy of issue and number of stakeholders
Many languages that reflect opinions from a larger group than those legally able to vote. participation includes:
- non-citizens,
- those on working on Visas and those who are disenfranchised by current voting system (i.e. youth)

You can turn back time and see the outcomes of past issues and the futures that never were

Awareness

Since the platform VISUALIZES the options being debated by policy-makers, the general public is made ware of civil dynamics in their day-to-day routine.

Learning Goals

- Make alternatives visual
- Help bring an understanding of cause and effect to civil issues
- Increase participation in civic discourse
- Increase policy transparency

Site Extents

- First within downtown Toronto then larger area
- Urban context: The system has a certain threshold of people to interact with it.

Fig. 7.2 Example of a design idea from the Knowledge Media and Learning course, where students applied ideas of ubiquitous computing to the very wide knowledge community of a local urban democracy in Toronto, Canada

provides one illustration of a design idea from 2010 called "ALTCity," which proposed an ubiquitous computing application to support local democratic discussions, public, and personal visualizations.

The design projects are an important aspect of this course, as they require students to apply the community knowledge base in creating a new application of these various media for a knowledge community of their choosing. Students are not required to actually build these new media designs (although in some cases, they have developed prototypes), but rather to provide rich design descriptions, including drawings, specifications, and scenarios. Working in groups of three or four, each team is first asked to specify the knowledge community for whom the media product would be designed (e.g., new parents, high school chemistry teachers, driving commuters, home shoppers). Then, the team defines the learning or knowledge building goals (e.g., for commuters to learn about the geography they are driving through, and also to share and aggregate strategic commuting information). Students benefited from reviewing the design ideas from previous course offerings, which now form a small library of designs from across five course enactments.

This course has been a success, cited by many students as one of their favorites and by some as having transformed their way of thinking about learning and instruction. The course content improves each year, by design, as students synthesize all previous content, add new content elements, and extend each of the themes a bit further than in previous years. The presence of the instructor as a persistent feature of the course is one additional means of quality assurance, as the wiki pages for the various knowledge media themes become more populated with examples, better organized, and re-interpreted.

There has also been a clear benefit from having all previous design projects available to review before students brainstorm their own new designs. Designs have grown more nuanced with each year, starting with very basic concepts (e.g., a digital book reader) and progressing to increasingly complex, social designs (e.g., eHealth communities, democracy visualizers, or virtual collaborative reading rooms). Any analysis of the sophistication of designs would surely reveal progress from year to year, as each cohort of students has all previous designs to inform their understandings, and the instructor has one more year's experience to allow him to better guide the design process. Here is one student's (anonymous) comment from the reviews of a recent offering:

> This is the first course I have taken in my graduate program that actually used the knowledge building pedagogy. This was such a welcome departure from my conventional course work. I have found this to be one of the most mind expanding and collaborative classes that I have ever experienced, and feel that I am literally building on the ideas of those who came to this course in years before. The course has certainly altered my ideas about education in so many ways, and for that, I am very grateful.

This is not an instructional design that could work for most contexts, even at the university or graduate level. However, it illustrates the powerful role that a wiki can play in supporting collaborative designs; in allowing students to create their own content, organization, and pedagogical content; and in representing this knowledge in a form that is accessible to future cohorts of students. The course is still maturing, and each year we hold a dinner where students from that year's course offering gather with those from previous years to discuss how the course might be improved. The wiki is always at the center of those discussions.

Exemplar 2: A Drupal Community for a High School Climate Change Curriculum

Our second exemplar is a 12-week high school curriculum unit on the topic of Global Climate Change, which is a major section of the Ontario (Canada) tenth grade science expectations. This unit was designed as part of a research study, where we added an epistemological treatment to KCI, as well as social tagging (i.e., keywords) and more sophisticated collaborative inquiry designs. We employed Drupal as a content management system because of its capabilities to define structured content (e.g., Web pages with several distinct sections, each of which could be tagged by students separately from the others) and its overall flexibility in enabling complex collaborative designs (e.g., different groups of students creating, viewing, and editing various forms of content, using that content as a knowledge base for collaborative inquiry projects). Drupal provides easy authoring of structured content, tagging and voting activities, and coordination of groups, including membership and permissions for viewing and editing.

Our main goal was to design a global climate change curriculum unit that met KCI design principles, as well as the curricular expectations for the Ministry of Ontario, and the specific framework of the school science department. We ran this curriculum with 109 students from five separate sections of science class, administered by three teachers who were also part of the design team. The ratio of computers to students in both class sections was one to one, with good Internet connectivity.

We describe the curriculum in terms of three phases, generally corresponding to the principles of KCI. In the first phase, we oriented students to the nature of this learning design and helped them establish connections to prior relevant experiences (e.g., from Wikipedia, gaming, or other online activities). The second phase entailed the creation of a community knowledge base, which was achieved through a sequence of collaborative inquiry activities. This work resulted in the steady growth of pages, links, tags, and comments within the Drupal site, all organized according to a set of 14 Canadian climate change issues. The final phase was a culminating inquiry project where students again worked collaboratively within small groups to develop a climate change remediation plan, making use of the knowledge base and indexing to the important science learning goals.

Phase 1: Establishing a Collaborative Culture and Epistemological Frame

In the first several meetings, students watched a video about the impact of climate change on the lives of indigenous people in the Northern territories of Canada. They then studied regional climate change in small groups and became more familiar with potential problems and regional implications. Following these introductory sessions, we held an in-class discussion on the nature of science, emphasizing how important it is for modern day scientists to be able to collaborate and aggregate their efforts. We used the Human Genome Project, the International Space Station, ocean floor mapping, and climate change science as examples. Our discussion emphasized the idea of shared responsibility for knowledge advancement, orienting students to the collaborative nature of our curriculum and the importance of our shared knowledge base. We engaged students in a "References" activity, where they were introduced to the notion of collaboratively creating a collection of resources and references that would be available to all members of the course. Students were reminded that all activities within this curriculum unit were interdependent, so that the outcome of any activity would likely influence future activities (their set of collected references and resources was a good example).

Phase 2: Collaborative Knowledge Construction

The first collective inquiry activity was a brainstorm, where each class section built on ideas received from the previous section as their starting point. The purpose of this activity was to synthesize students' ideas about climate change issues into a series of topics that would serve as a basis for subsequent collaborative inquiry (i.e., to meet the KCI design principle that themes from the community should be accommodated in the design of inquiry activities). Students in the first class section began by writing their ideas about climate change issues on Post-it notes, spreading the note onto large sheets of paper. Those sheets were then passed on to the next section, where students read their peers' notes and added new ones, and then to the next section, where students added new notes again and began sorting them into thematic piles. In the fourth section, students finished sorting piles of Post-it notes into thematic groups, and then named the groups. The final section took the paper contents and began summarizing each theme into a Drupal "Issues" page, which was given to the teachers who combined a couple of issues and split others into constituents. This process resulted in a set of 14 "Issue Pages" that reflected the students' collective voice. It is worth noting that this activity could have been done using a Web 2.0 technology (Wiki or special Drupal page). However, the teachers wanted a physical medium that could be manipulated, and Post-its with butcher paper worked just fine.

The basic structure of the climate change unit was such that each Issue group included members from two or more of the five class sections (approximately eight students per group). The students within a group were responsible for collaboratively editing their group's issue page, according to its major headers. The first three headers were designed to ensure that students focused on the relevant climate change science (i.e., greenhouse gases, thermal energy circulation [in the atmosphere and oceans], and carbon sinks and sources). For each of these headers, students were instructed to add a discussion of the scientific aspects of their climate change issue. The fourth header dealt with scientific evidence with a particular emphasis (guided by the teacher during instruction) on the outcomes of models and simulations. Students were asked to add such evidence to this section of their page. The final two headers were about existing social responses to the issue, including any current legislation, as well as existing remediation efforts and their evaluation. Students who were members of a given issue group could edit and tag its various sections. All other students could view or add comments to the page.

To facilitate students' retrieval of relevant knowledge within these (voluminous) issue pages, keyword tagging was enabled for each independent sub-section of the page (i.e., as opposed to just tagging the whole page). In addition to these sophisticated Drupal pages for climate change issues, the following technology scaffolds were developed in Drupal:

- A *Group Planning Page* to support the group in planning, assigning roles, monitoring progress, and addressing problems related to group dynamics or quality of content.
- *Embedded Reflection Notes* to help students reflect on their contribution to group work, including the scientific quality of their contributions, and to make personal connections to the activities.

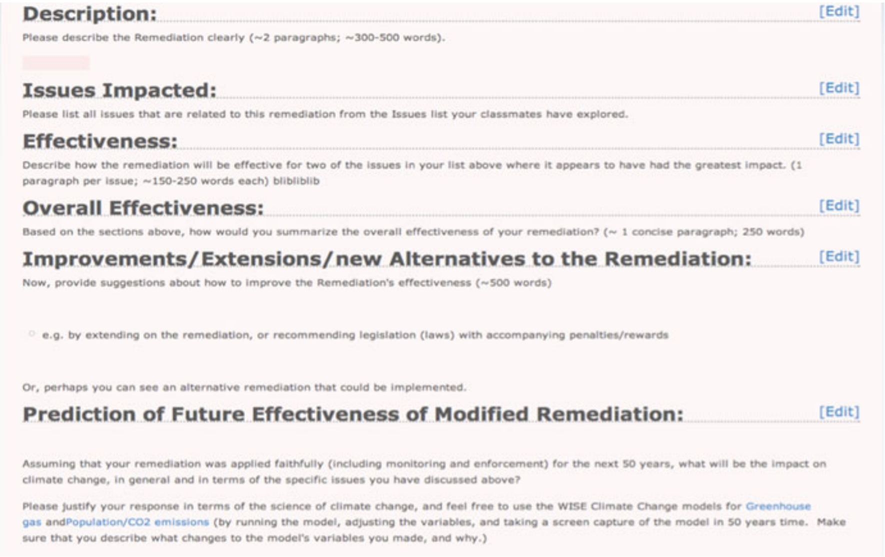
Table 7.1 Revisions and word count for issue pages

Page	# of revisions	# of editors	# of words
Alberta tar sand	56	7	3,418
Deforestation	93	8	2,829
Desertification	208	6	3,133
Economy	85	7	4,406
Glaciers melting	44	6	1,811
Individual actions	58	7	2,830
Natural disasters	99	8	4,839
Ocean warming and thermohaline circulation	77	6	2,678
Polar amplification	56	8	2,208
Pollution and greenhouse gases	78	6	3,442
Rising of the sea level	79	7	3,302
Tropospheric ozone	89	6	4,278
Unusual/extreme weather	164	7	5,333
Wildlife	74	8	4,621

- A *Peer Review* scaffold, where students provided feedback to other groups concerning gaps, connections, or potential improvements to their issue pages. The peer review activity helped to raise students' awareness of the knowledge being developed within other issue pages.

Over a 6-week time span, students addressed each aspect of climate change science on their issue page in conjunction with other instructional activities (lectures, labs) that addressed those topics in sequence. The KCI objective of this phase was for students to co-construct a knowledge base that would be used in future inquiry activities. Students within each issue group added ideas to their page, building on ideas contributed by others from their group. Functionally, this was quite similar to a wiki, as students could just click "edit" for their page to add images, links, and keyword tags of their choosing. There were also five individual student reflections (implemented as simple Drupal surveys) and a peer review activity. The outcome of this phase was a collective knowledge base that fully described all 14 issues (and their science connections) that the community could employ in subsequent inquiry activities.

The sophistication and completeness of the issue pages that emerged from this activity were remarkable. The pages included dozens of screens of text and images, and thousands of words, with many edits made by nearly 100 % of all participating students. Table 7.1 offers a summary of these basic authoring statistics. However, no statistics can do justice to the impressive knowledge base that was constructed by students working across five sections of a course in 6 weeks' time. This knowledge base was impressive to the students and teachers as well, and all students felt they



Description:

Please describe the Remediation clearly (~2 paragraphs; ~300-500 words).

Issues Impacted:

Please list all issues that are related to this remediation from the Issues list your classmates have explored.

Effectiveness:

Describe how the remediation will be effective for two of the issues in your list above where it appears to have had the greatest impact. (1 paragraph per issue; ~150-250 words each) bliblibib

Overall Effectiveness:

Based on the sections above, how would you summarize the overall effectiveness of your remediation? (~ 1 concise paragraph; 250 words)

Improvements/Extensions/new Alternatives to the Remediation:

Now, provide suggestions about how to improve the Remediation's effectiveness (~500 words)

○ e.g. by extending on the remediation, or recommending legislation (laws) with accompanying penalties/rewards

Or, perhaps you can see an alternative remediation that could be implemented.

Prediction of Future Effectiveness of Modified Remediation:

Assuming that your remediation was applied faithfully (including monitoring and enforcement) for the next 50 years, what will be the impact on climate change, in general and in terms of the specific issues you have discussed above?

Please justify your response in terms of the science of climate change, and feel free to use the WISE Climate Change models for Greenhouse gas andPopulation/CO2 emissions (by running the model, adjusting the variables, and taking a screen capture of the model in 50 years time. Make sure that you describe what changes to the model's variables you made, and why.)

Fig. 7.3 Technology scaffold for remediation plan pages

would be able to use the contents from the knowledge base as a resource in subsequent inquiry activities.

Phase 3: Utilizing the Community Knowledge Base

The third KCI principle states that inquiry activities should guide students in applying ideas and resources from the community knowledge base, emphasizing the underlying science (or relevant domain) content and producing assessable outcomes. We designed a culminating small group inquiry activity where students examined strengths and shortcomings of the remediation efforts described on the issues pages, and either suggested improvements to those remediations or proposed a new plan altogether. This activity was conducted by groups of students from within a class section to facilitate assessment. Students were required to examine the effectiveness of their selected remediation plan with respect to all relevant issues in the knowledge base (i.e., not just the one for which it may have been initially reviewed). They were asked to suggest improvements to the plan and to predict the impact of the plan in the future—ideally, using a scientific forecast model (with which they had gained some familiarity and experience during the course).

To scaffold this activity, we developed a Drupal page with a collection of independently editable segments, allowing several group members to edit the page at once (see Fig. 7.3). The sections included detailed instructions (in italics, below the sub-header), to guide students' focus and encourage the re-use of material from the knowledge base.

Once again, student participation in the culminating project was remarkable. Most impressive was learners' use of ideas from the community knowledge base to support their remediation plans. We will be writing many pages about our analysis of student learning and our evaluation of KCI in forthcoming scientific publications. For this chapter, however, we provide the basic curricular design as an exemplar of how Web 2.0 technologies can be integrated into a curriculum design that promotes collective and collaborative learning.

Next Steps

The two exemplars illustrate curricula that were developed according to the principles of KCI. These designs were implemented using several different technology platforms (including Post-it notes and butcher paper!) with no need for sophisticated data mining or intelligent agent techniques, recommender systems, or elaborate social networks. The activity and interaction designs were accessible to teachers and students alike, and everyone involved had a reasonable understanding of the overall curriculum.

One commonality between the two exemplars is the huge amount of effort required for their design and development. The first involved an entire semester plus a whole summer for the instructor, just to define the basic activity sequences that would be conducted. The second involved the design of more complex, carefully designed inquiry activities and technology systems, including nearly 2 years of meetings, development effort, and a major pilot version. Thus, we are under no misconception about the level of effort, creativity, and iterative refinement required to establish such designs. Still, the most challenging aspects are pedagogical in nature: given all the time in the world, we still need to understand how to design our instruction so that it is effective and engaging. As a model, KCI provides some guiding principles for designing knowledge community curricula, and a reference against which to evaluate the enactment of those designs (Peters & Slotta, 2010).

In our first exemplar, students experienced a very different form of learning than they would have obtained from a more conventional university seminar design. The main goal of this curriculum was for students to advance knowledge about various new media and media practices—a goal for which the knowledge advancement pedagogy was clearly well suited. Our design also advanced pedagogical content knowledge, contributed by students in the form of designs where the class learned about various media through using them. Moreover, it advanced our understanding of how a wiki could support students' collection and representation of such knowledge as a resource for those who come along in following years.

The second exemplar engaged students from five class sections, usually taught in complete separation from one another, in creating a wiki that grew into a comprehensive knowledge resource for everyone. Students were engaged in creating their chosen issue page, and were challenged to apply the specified science dimensions in their final projects.

However, creating a knowledge community in a secondary science classroom (or across multiple classrooms) is not something that can be done simply by using a set of activities, technology environments, or even design principles. One could argue that (a) it might not really be *possible* to achieve a real sense of collective epistemology and inquiry without the complete transformation of the educational system, or alternatively that (b) at some level, *all classrooms are knowledge communities* and collective inquiry is more common that we might think.

After several years of close collaboration with high school teachers to create multi-week curriculum units that engage dozens of students across multiple sections of a course, we find ourselves acknowledging both of these arguments. The students were clearly engaged in the activities, embracing them quite naturally, and learned quite a bit along the way. The teachers were able to coordinate the curriculum, aided by the technology environment, and still have confidence that the science content expectations had been achieved. In other words, the KCI model performed reasonably well, leading to a design that supported collective inquiry and knowledge integration. However, it was evident that these activities all occurred within the broader "surround" of normal school days, with a normal context of assessment, within an extremely competitive and achievement-oriented student body. We cannot claim that students' educational experience or environment was radically transformed, and it is clear that such environmental variables are a major challenge to any knowledge community approach.

Still, change comes gradually. With KCI—a model developed explicitly for the purpose of bringing such activities to a modern secondary science course—we were able to produce an educationally relevant, engaging, and effective set of activities that added some new pedagogical and epistemological texture.

There are many challenges to the design or adoption of Curriculum 2.0 activities in K-12 schools, including the institutional constraints of time schedules, testing requirements, class size, and access to computers or Internet. However, there are also firm conceptions of learning and instruction held by both students and teachers, concerning the nature of curriculum and assessment. Teachers require experience with any new pedagogical approach to develop fluency and eventually mastery of that approach. Hence, pre-service and in-service professional development programs would be required, including well-documented designs, classroom video, design frameworks, and in-service mentorship. But once again, the greatest obstacles are concerned with our understanding of the basic pedagogy and our definition of reliable design principles. As a field, we are still in the early stages of understanding how such learning occurs. It would be premature to claim that all learning should occur in this way, or that schools should be transformed to enable it. Perhaps this will occur in the remote future, but for now we are still exploring the early examples of learning as knowledge communities.

Our work begins with the supposition that the collaborative and aggregative media of Web 2.0 are best suited to learning designs where students work as a collective body, contributing, sharing, and co-developing resources, reflecting on the results, and maintaining a sense of progress of the community as a whole. Our early experiences with such learning, which have taken more than 5 years to unfold, have demonstrated to our satisfaction that this supposition is a good one. Students and instructors have much to gain through such designs. But teachers will not change their methods of instruction all at once nor will students change their expectations about learning all at once. Rather, we must all take small steps—and most likely some false steps—to gather sufficient experiences with such learning, to develop a shared language and representation about their design, and to forge new expectations about what constitutes a good learning design.

A Web 2.0 community could actually play an important role in this collective effort, supporting a knowledge community where educators share materials and approaches, vote for effective designs, and form circles of shared interest and expertise. High school science teachers are already forming circles, sometimes in conjunction with their professional associations. Summer and in-service workshops are representing their products online, and curricular communities are forming within Facebook for many disciplines. Indeed, we should be surprised if networks of teachers did not begin to advance their own knowledge about Curriculum 2.0 approaches.

We have presented examples and discussion concerning our own recent experiences with new forms of learning and instruction. KCI has been advanced as a fairly pragmatic model, still in its early stages, even as Web 2.0 itself is still in the early stages. At the time of this writing, curriculum design of all forms is entering a time of innovation and evolution. Hence, it is most prudent to focus on broad pedagogical principles and not become too committed to any specific approach or technology. Finally, it is always best to consider the learning goals and instructional activity design before making any commitments to specific technology. Certainly, one should avoid the inverse approach, where we start by identifying specific technologies like blogging or wiki and trying to find ways to add them to our instruction (e.g., in the name of technology integration). When considering why we would integrate Web 2.0 technologies (before we consider how to integrate them), the most important pedagogical reasons would be to connect students to their peers and make learning more social and engaging.

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Chapter 8
Networked Technologies to Foster Students' Collaboration and Reflection

Eleni A. Kyza

Today's world is characterized by an unprecedented technological transformation. According to Castells (2000), we are witnessing a digital revolution, which is leading to a re-organization of the social, cultural, and economic aspects of what is now called by many "a network society." The goals of education need to be re-conceptualized (Collins & Halverson, 2009) and new information age skills must be developed in response to the increased importance of complex thinking skills in this context. Additionally, educational practices must be aligned to our current understanding of how people learn (Bransford, Brown, & Cocking, 1999). It is now well established that the educational enterprise should focus on knowledge building as a means for making sense of the world. These issues must be kept in mind when adopting, adapting, or developing technologies for the purposes of teaching and learning.

This chapter focuses on the use of networked technologies to support the development of two increasingly important and complex skills for learning in the twenty-first century: collaboration and reflection. The chapter begins with a definition of key concepts as they relate to networked technologies. Two exemplars of networked technologies that can support reflective, collaborative thinking and appear to have the potential to transform the learning process are presented next. The chapter concludes with a discussion of the implications for integrating these technologies into teaching practice.

E.A. Kyza (✉)
Department of Communication and Internet Studies,
Cyprus University of Technology, Limassol, Cyprus
e-mail: eleni.kyza@cut.ac.cy

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Background

Defining Networked Technologies

Networked technologies are defined as the Information and Communication Technologies (ICT) used to support connections between people: between learners, between learners and teachers, and between learners and resources (Goodyear, Banks, Hodgson, & McConnell, 2010). The term "networked technologies" is usually associated with online learning, particularly in the context of higher education and adult learning settings. This represents a narrow and limiting use of the term. In this chapter, the term is used to refer to the networked aspect of technology-enhanced learning in the context of K-12 education.

Networked technologies for learning encompass a broad range of Internet-based tools including online simulations, specialized learning platforms, multi-user virtual environments (MUVEs), and the types of applications collectively known as Web 2.0 applications (e.g., blogs, forums, wikis). Such technologies can enhance learning when used in accordance with principles that guide cognitive and social development, including (a) fostering students' active and reflective engagement, (b) providing opportunities for collaborative learning, (c) involving students with real-world contexts, and (d) providing just-in-time feedback (Bransford et al., 1999; Roschelle, Pea, Hoadley, Gordin, & Means, 2000).

In particular, networked technologies can support a seamless integration of multimodal information such as text, images, video, and audio, while hyperlinks can connect nodes with one another, making learning more authentic and cognitively engaging to students. By transcending temporal and geographical constraints, such technologies also allow learners to collaborate synchronously and asynchronously while in different locations around the globe. Networked technologies can often facilitate flexible learning and involvement with real-world contexts by allowing easy customization and personalization of resources while at the same time functioning with different operating systems with minimal modifications (Linn, 2003). Finally, these technologies can also facilitate timely communication, providing opportunities for just-in-time feedback, which can increase learner engagement, participation, and collaboration (Greenhow, Robelia, & Hughes, 2009).

Learning for the Twenty-First Century

The U.S. National Research Council (2010) highlights complex communication and social skills, non-routine problem-solving, and self-management and self-improvement skills as three of five key areas of learning in the twenty-first century (adaptability and systems thinking are the other two). Networked technologies can foster the development of such skills, knowledge, and understanding, which are required to respond to the needs of a rapidly changing society. These areas (complex communication and social skills, non-routine problem-solving, and self-management skills) are explored in the next section as they relate to networked technologies. The two exemplars described later in this chapter represent technologies that can foster the development of what has been identified as twenty-first century skills.

Complex Communication and Social Skills

Networked technologies can contribute to the development of communication and social interaction skills by facilitating students' collaborative knowledge building processes using synchronous and asynchronous online tools. Collaborative learning refers to a situation where peers work and learn together as they solve problems (Damon, 1984). Peer involvement is acknowledged to be an important part of child development. In line with Vygotsky's (1978) socio-cultural theory of learning, collaborative learning affords peer interaction, which can gradually lead to intersubjectivity, namely, the state at which shared understanding between two or more persons has been achieved. This social interaction can support knowledge building beyond the level of individual cognition (Scardamalia & Bereiter, 2006) and can help learners become knowledge creators and active participants in learning communities. According to Scardamalia and Bereiter (2006), knowledge building should be focused around the creation and negotiation of epistemic artifacts (e.g., model or theory development, experimental designs, etc.).

Pragmatic and cognitive considerations are contributing to the increasing popularity of collaborative knowledge building. Both types of considerations serve distinct goals. Pragmatic considerations cater to a real-life need for developing skills to participate in multi-disciplinary groups to solve complex problems. Cognitive considerations respond to research findings indicating that peer collaboration can improve learning (Bowers, Pharmer, & Salas, 2000; Johnson & Johnson, 1989; Slavin, 1990; Webb, 1982), even creating opportunities for learning that are not achievable in individual learning situations provided certain conditions are met. Peers working together participate in situations affording activities that require actions such as cognitive elaboration, articulation of explanations, and mutual regulation, which, in turn, can trigger cognitive mechanisms associated with learning (Dillenbourg, 1999). Opportunities for interaction afforded through networked technologies such as argumentation, collaborative elaboration of ideas, and presentations among others have the capacity to support students in honing on their social skills (National Research Council, 2010). Even though the effects of collaborative learning cannot be predicted as they depend heavily on several contextual factors, such as the learning environment and the quality of peer interactions, creating opportunities for collaboration through careful design is feasible. Design can involve the development of pedagogical activity sequences as well as the design or adaptation of computer-based learning environments.

Computer-supported collaborative learning (CSCL) developed as a distinct subject of study as a result of increased attention to the socio-cultural aspects of learning

(Stahl, Koschmann, & Suthers, 2006). CSCL should not be confused with what is usually defined as "e-learning." One can identify two main differences between CSCL and e-learning approaches. Firstly, while e-learning mainly attends to technological infrastructure and delivery of digital information, CSCL focuses on the use of technology to augment human interaction on purely online learning environments, during face to face (f2f) interactions, or in blended learning situations. Secondly, the interaction between human (teacher, students) and technological agents (software tools), and the facilitation of this interaction via structuring and scaffolding are crucial aspects of the CSCL approach; such issues may not receive adequate emphasis in e-learning contexts.

Non-routine Problem-Solving and Self-Management Skills

Non-routine problem-solving is a characteristic of expert thinking; it integrates a deep conceptual understanding of a domain with a creative, systematic, and reflective approach to examining and synthesizing diverse data (National Research Council, 2010). Networked-based technologies can support non-routine problem solving by providing the tools and the scaffolding that allow learners to engage with extended and data-rich investigations. For instance, online participatory simulations, such as NetLogo (Wilensky & Stroup, 1999), allow individual students to use handheld or networked computers to model complex systems, such as the spread of a disease in a population over time, while the aggregated behavior of the class can be displayed on a larger display for collaboration and reflection at the level of systems thinking (see Chap. 6, section "Exemplar 1: Collective Activity in Classroom Networks" for another example). Tools like NetLogo can empower learners, allowing them to explore multiple pathways and different lenses to solving problems.

Self-management skills refer to students' ability to motivate themselves, monitor their understanding, work autonomously, collaborate with others, and have the skills and desire to self-improve by acquiring new knowledge and skills (National Research Council, 2010). Self-management skills are necessary in achieving self-regulation, which describes a state in which students have the skills to control the motivational, emotional, social, and cognitive components of their learning (Bandura, 2006). Current understanding of how people learn advocates moving away from instructionist teaching methods towards constructivist learning (Bransford et al., 1999), which places the students in control of their learning. In constructivist environments, learners are expected to assume more responsibility for their own development and to engage in reflective thinking, a process that facilitates the acquisition and development of self-regulation. Dewey (1933) argued that reflective thinking distinguishes intelligent behavior from impulsive actions; it is deliberate and rigorous. According to Rodgers (2002), four characteristics are at the heart of Dewey's notion of reflective thinking: Reflection (a) is a quest for personal meaning making; (b) is a systematic and iterative process; (c) happens in the context of interacting with others, especially while explaining one's thoughts; and (d) is mediated by one's attitudes towards learning. Technologies that help shift the responsibility for learning from the teacher to the learner and place the learner in collaborative settings to promote reflective interactions assume an important role in promoting learning in the information or network society.

Despite frequent discussion of the need for reflection in educational praxis, the construct is often elusive, making the enterprise of designing learning environments for the purpose of reflection somewhat challenging. Two types of reflection have been identified in the literature: reflection-*on*-action and reflection-*in*-action. Although Schön (1983) introduced these two terms in the context of teacher learning, they easily apply to student learning, particularly when students assume an active role in their learning and are faced with challenges that require increased responsibility and decision-making. *Reflection-on-action* can be interpreted as a summative construct, a recollection and evaluation of what has happened, after the events take place. In contrast, *reflection-in-action* can be seen as closely related to self-regulation; during reflection-in-action students are expected to engage in iterative sequences of planning, monitoring, and evaluating their actions as these relate to their problem-solving activity (Kyza, 2004). Thus far, much of the focus in the literature with respect to students' reflection has been on reflection-on-action. However, the need for students to develop self-regulation as a twenty-first century skill means that scholars and educators should pay closer attention to ways in which reflection-in-action can be fostered.

Exemplars

This section discusses two exemplars of networked learning technologies that afford student collaboration and reflection online. The exemplars were chosen because they represent open-ended, interdisciplinary tools that can help meet the challenges of twenty-first century learning, can be adapted by teachers to serve various learning situations in a variety of subject matters, are supported by research, and are easy to obtain. The first exemplar (STOCHASMOS) represents a genre of specialized web-based platforms specifically designed for pedagogical purposes to support reflection-in-action during online inquiry. The second exemplar (Wikis) represents a genre of tools that are based on Web 2.0 technologies and that can be adapted to support reflection-on-action. Both tools have features that can support collaborative learning, knowledge building, and reflective thinking.

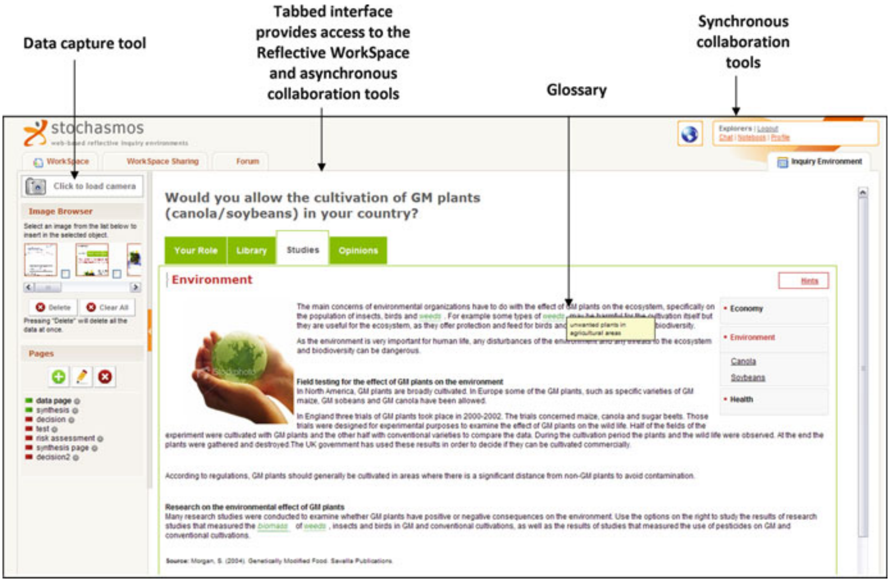
Exemplar 1: The STOCHASMOS Web-Based Platform to Support Collaboration and Reflection-in-Action

The first genre of networked learning technologies refers to technologies specifically designed to support innovative pedagogical frameworks that promote learning through student collaboration and reflection. These technologies differ from generic, commercial Learning Management Systems (LMS), such as WebCT or Blackboard, as they are strongly based on theories of how people learn and empirical research examining the enactment and affordances of the tools in real classrooms. STOCHASMOS (Kyza & Constantinou, 2007) is an example of a networked technology that was built to support collaborative learning and reflection-in-action.

The platform (www.stochasmos.org) consists of two environments: one dedicated to students' reflection during inquiry and the other to support teachers' authoring of data-rich investigations on the Web. The students' inquiry environment was designed to support small groups of students while engaging in self-regulated, scaffolded learning explorations of data-driven scenarios. In a typical scenario of use, students work collaboratively in groups of two or three on an investigation that their teacher either developed or adapted from an existing design. The investigation is data-driven and matches the students' skills, level, and broad interests. Data are presented in different forms and students are asked to interpret, integrate, and explain their data by producing evidence-based explanations to a given problem. Students' activity is guided by a driving question. For instance, sixth graders were asked to create an evidence-based report for the Fisheries department to explain the death of Flamingos in a local ecosystem and propose corrective measures (Kyza, Constantinou, & Spanoudis, 2011). Working in pairs, students generated and reviewed data in STOCHASMOS, which helped them learn about the local ecosystem. Each pair identified and automatically captured data that could help them answer the question, using the data capture tool. The data were organized and explained in the reflective WorkSpace. Students moved back and forth between the inquiry environment and the WorkSpace to identify and interpret data, link evidence to narrative, and create their final report.

Unlike commercial content management systems used in education, a key feature of the STOCHASMOS platform is the pedagogical design of the embedded tools to support the inquiry of complex datasets and collaborative reflection based on explanation building. The design lends itself particularly well to learning environments that focus on inquiry and evidence-based reasoning. Figure 8.1 highlights the main features of the students' inquiry environment in STOCHASMOS. The *data capture tool* depicted in this figure enables students to select, capture, and organize data as evidence in the *Reflective WorkSpace*, which is shown in Fig. 8.2. Teachers use the authoring tool of STOCHASMOS to create templates in the Reflective WorkSpace to guide their students in interpreting data, externalizing their ideas, and connecting explanations to data they have collected. Students can share their data pages and explanations with their peers, using two STOCHASMOS web-based collaboration tools (see Fig. 8.3): the *WorkSpace Sharing* tool for providing asynchronous peer feedback to other student groups and the embedded *chat tool* for collaborating synchronously. Student collaboration and reflection-in-action occurs as students, working in groups, alternate between the tabbed interfaces to identify, collect, and explain data to answer the driving question.

Research suggests that the interaction resulting from student pairs' iterative use of tools, such as the reflective WorkSpace, has the potential to support collaborative reflective inquiry, which requires that students plan, monitor, and evaluate their ongoing inquiry processes (Kyza, 2004). The analysis of conversations as student



Would you allow the cultivation of GM plants (canola/soybeans) in your country?

Environment

The main concerns of environmental organizations have to do with the effect of GM plants on the ecosystem, specifically on the population of insects, birds and weeds . For example some types of weeds may be harmful for the cultivation itself but they are useful for the ecosystem, as they offer protection and feed for birds and biodiversity.

As the environment is very important for human life, any disturbances of the environment and any threats to the ecosystem and biodiversity can be dangerous.

Field testing for the effect of GM plants on the environment
In North America, GM plants are broadly cultivated. In Europe some of the GM plants, such as specific varieties of GM maize, GM sobeans and GM canola have been allowed.

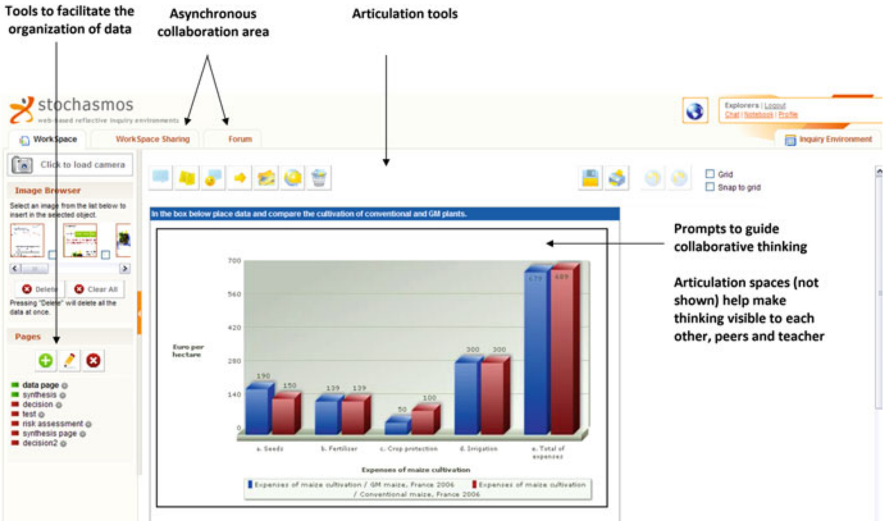
In England three trials of GM plants took place in 2000-2002. The trials concerned maize, canola and sugar beets. Those trials were designed for experimental purposes to examine the effect of GM plants on the wild life. Half of the fields of the experiment were cultivated with GM plants and the other half with conventional varieties to compare the data. During the cultivation period the plants and the wild life were observed. At the end the plants were gathered and destroyed.The UK government has used these results in order to decide if they can be cultivated commercially.

According to regulations, GM plants should generally be cultivated in areas where there is a significant distance from non-GM plants to avoid contamination.

Research on the environmental effect of GM plants
Many research studies were conducted to examine whether GM plants have positive or negative consequences on the environment. Use the options on the right to study the results of research studies that measured the biomass of weeds , insects and birds in GM and conventional cultivations, as well as the results of studies that measured the use of pesticides on GM and conventional cultivations.

Source: Morgan, S. (2004). Genetically Modified Food. Savella Publications.

Fig. 8.1 The STOCHASMOS inquiry environment



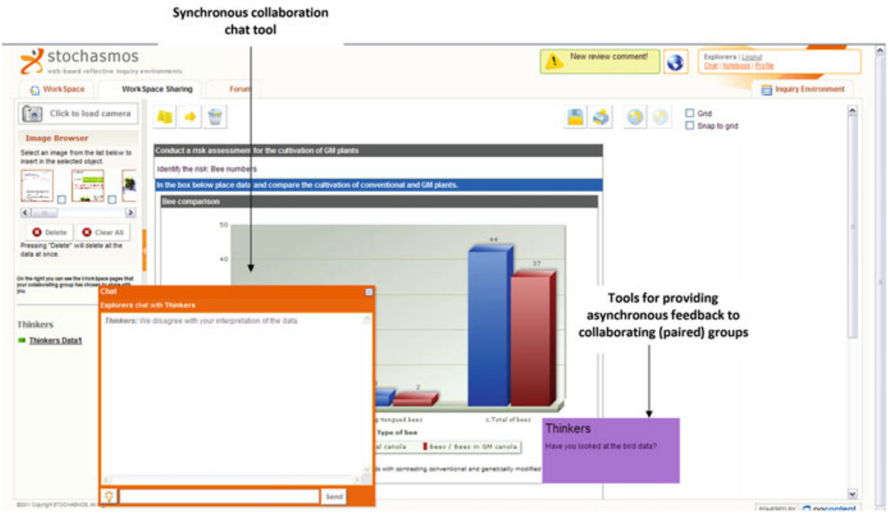
In the box below place data and compare the cultivation of conventional and GM plants.

Prompts to guide collaborative thinking

Articulation spaces (not shown) help make thinking visible to each other, peers and teacher

Fig. 8.2 The STOCHASMOS reflective WorkSpace

pairs were working in the WorkSpace during the Flamingo investigation indicated that the scaffolding provided by the tools promoted reflection about the data students had collected and supported the progress of their investigation, thus stimulating reflection-in-action. The following excerpt is illustrative of this process (student names are pseudonyms). In this excerpt, students are examining data they have



Synchronous collaboration chat tool

Tools for providing asynchronous feedback to collaborating (paired) groups

Select an image from the list below to insert in the selected object.

Pressing "Delete" will delete all the data at once.

Conduct a risk assessment for the cultivation of GM plants

Identify the risk: Bee numbers

In the box below place data and compare the cultivation of conventional and GM plants.

Explorers chat with Thinkers

Thinkers: We disagree with your interpretation of the data.

Thinkers

Have you looked at the bird data?

Fig. 8.3 The STOCHASMOS WorkSpace sharing tools

interpreted so far in connection to hypotheses they had earlier articulated in the Reflective WorkSpace. In the process of creating an evidence-based explanation, students come to engage in different types of reflection, as indicated in the column titled “Reflection-in-action.”

		Reflection-in-action
1	Randy: We can’t find any evidence for this [one of their hypotheses]. There isn’t any.	Monitoring
2	Christine: How do you know?.	Monitoring
3	Randy: Our second hypothesis is that some birds [might have died] from a disease some other birds might have brought, like the bird flu, and in this way the disease was transmitted to all the flamingos at the Larnaca Salt Lake.	
4	Christine: Let’s find evidence for this [hypothesis].	Planning
5	Randy: But it doesn’t make any sense.	Evaluating hypotheses
6	Christine: For me it does.	
7	Randy: None of our hypotheses makes sense.	
8	Christine: This means that even the one you found evidence for is not valid.	
9	Randy: Let’s go find evidence. We may find some evidence.	Planning

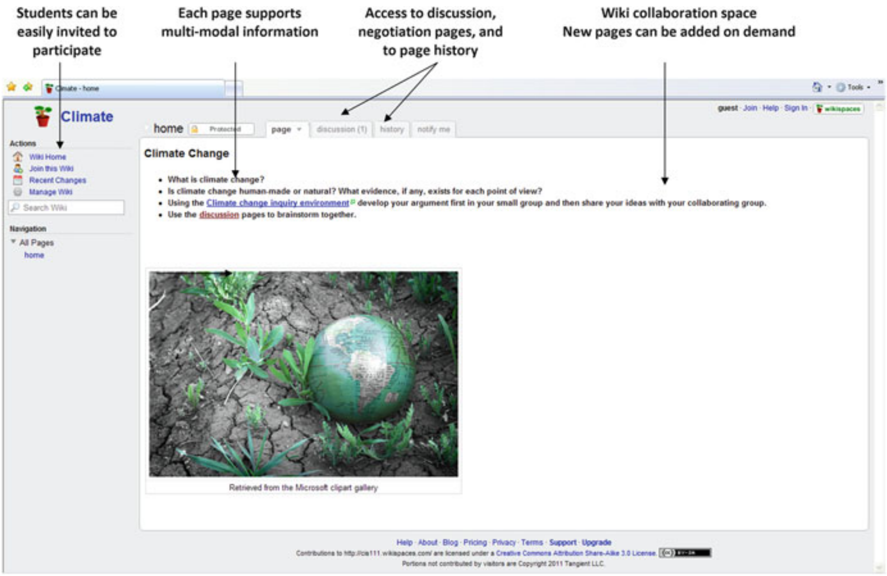
STOCHASMOS can be used in a variety of contexts that require students to engage in inquiry-based learning and produce evidence-based arguments (e.g., history, science education, literacy). Research studies show that the STOCHASMOS platform is effective in supporting students' collaborative development of evidence-based explanations and reflective inquiry in science education settings, as illustrated by the students' discourse discussed earlier in this chapter. Furthermore, Kyza et al. (2011) found statistically significant results on conceptual understanding and elementary students' collaborative explanations of socio-scientific problems, such as the Flamingo problem. Nicolaidou, Kyza, Terzian, Hadjichambis, and Kafouris (2011) found that the scaffolding provided in a Biotechnology learning environment available in STOCHASMOS and the activity sequence developed in collaboration with the teacher supported high school students' development of skills in assessing the credibility of evidence and their conceptual understanding of biotechnology concepts.

Exemplar 2: Wikis in Support of Collaboration and Reflection-on-Action

The second genre of networked technologies that have the potential to support collaboration and reflection are Web 2.0 tools. Web 2.0 applications are extremely popular because of their participatory and social interaction affordances. Even though they were first developed for non-educational purposes, they have recently begun to infiltrate classroom learning. Examples of such applications include wikis, podcasts, blogs, and social network applications. The primary characteristics of such technologies are user-generated content and user participation, which provide the basis for the social interactivity behind Web 2.0 applications. Barab and Dede (2007) identified three functions of such technologies in support of learning: sharing, thinking, and co-creating. As they inherently feature multi-user participation, Web 2.0 technologies can provide the infrastructure for online collaborative learning and can afford the creation of online communities and communities of practice (see also Chap. 7, section "Inquiry Oriented Knowledge Communities"). In particular, the asynchronous capabilities of these tools allow time for reflecting-on-action, either on one's own work or on someone else's.

The focus in this chapter is on wiki technology. In simple terms, wikis are web pages that can be asynchronously edited by different users. In contrast to blogs (in which users can only respond to comments posted) and threaded discussions (such as the ones found in forums), the wiki architecture supports the asynchronous co-construction of work and includes features, such as versioning, that allow the attribution of individual work. In many ways, the driving force behind wikis is the creation of a community of learners working together on a joint project (see also Chap. 7, section "Exemplar 1: Use of Wikis in Higher Education"). Figure 8.4 illustrates a typical wiki page structure.

There are many wiki-hosting services (or wiki farms) that anyone can use to author his or her own wiki environment. Several of these services provide free wiki hosting for educators (e.g., MediaWiki, WikiSpaces, and Google Sites, accessible respectively at http://mediawiki.org, http://www.wikispaces.com/ and http://www.google.com/sites). Perhaps the most well known example of a wiki is Wikipedia (www.wikipedia.org), developed with the MediaWiki hosting service. However,



Climate Change

- What is climate change?
- Is climate change human-made or natural? What evidence, if any, exists for each point of view?
- Using the Climate change inquiry environment develop your argument first in your small group and then share your ideas with your collaborating group.
- Use the discussion pages to brainstorm together.

Retrieved from the Microsoft clipart gallery

Contributions to http://cis111.wikispaces.com/ are licensed under a Creative Commons Attribution Share-Alike 3.0 License.

Portions not contributed by visitors are Copyright 2011 Tangent LLC.

Fig. 8.4 A Wiki page hosted on Wikispaces.com

integrating wikis into classroom practice requires careful preparation and goes beyond asking students to work together to produce a story. In contrast to tools, such as STOCHASMOS, which embody a pedagogical philosophy and can serve as boundary objects (Star & Griesemer, 1989) thus bootstrapping the process of learning, tools like wikis have to be integrated within a pedagogical activity sequence that can support collaborative knowledge building.

For example, a project in South Dakota used the Twiki platform (http://twiki.org/) to design a multi-school collaboration involving 11 school districts and almost 400 middle school students to investigate different issues relating to the Missouri river (Engstrom & Jewett, 2005). School teams were formed and grouped by project coordinators into small research teams based on the issue they chose to investigate. Each of the research groups' wiki pages included prompts to support the investigation and co-editing of pages, thus providing essential scaffolding of the writing process. The results of this project, which was titled "Under Control: The Damming of the Missouri River" (Engstrom & Jewett), highlighted the areas in need of support in order for wikis to be used in the classroom. Specifically, Engstrom and Jewett (2005) reported that one of the biggest challenges was structuring teachers' interactions with students to support critical thinking, such as prompting student asynchronous conversations.

In another study, 25 elementary school students aged 9–10 designed a MediaWiki space to document their evolving ideas as they investigated the feasibility of colonizing Mars (Pifarré & Kleine Staarman, 2011). Pairs of students working together first researched the topic using a WebQuest, an inquiry-oriented online learning activity, and wrote their initial proposals on the topic. In the next phase of the work, two larger groups, consisting of three pairs each, were created, and they worked together on the wiki to co-construct their argument. The collaborative work was supported by the design of the wiki, which was divided in two frames: one for composing the arguments and one for negotiating between groups. The researchers reported that student pairs first negotiated and then took turns in composing the collaborative text in the wiki, adding and refining what the other groups wrote. The analysis of the data collected provided positive evidence that the groups collaborated evenly to co-construct their proposal in the wiki and that the task setup provided opportunities for productive dialogues and the building of intersubjectivity.

Next Steps

Networked CSCL can provide unlimited opportunities for learning beyond borders. Choosing technologies that can afford social interaction and asking students to work collaboratively are desired. However, these actions are not enough for true collaboration and reflection; learning environments and teachers must guide students in collaborating and reflecting for these outcomes to be achieved (Grant, 2009; Kreijns, Kirschner, & Jochems, 2003). Such guidance can, for example, be provided by the teacher during online and offline activities or by carefully structuring students' task. Student groups should be scaffolded and their work should focus on creating epistemic artifacts. In turn, these tasks can function as motivating forces for collaboration while artifacts can become the object of systematic reflection. Roschelle, Knudsen, and Hegedus (2010) proposed that the successful integration of new technologies in the classroom should address the following three issues: (a) representational and communicative infrastructure, (b) curricular activity systems (see Chap. 2, section "Curricular Activity Systems," for additional information), and (c) new classroom practices and routines. Reform discussions often focus on new media and their transformative power. However, the history of failed educational innovations makes clear that technology should be approached from a human-centric perspective and informed by research on how people learn, if it is to have any impact on human society.

Teachers, in particular, have a critical role to play in supporting collaboration and reflection using networked technologies, beginning with planning the lesson activity all the way to implementing and evaluating the impact of the activity. Prior to implementation, teachers need to attend to issues specific to the types of technology being used. In this case, one would have to consider the following: sufficient access to computers and the Internet, whether the chosen technology matches the intended learning goals, and students' familiarity with the technology.

Emerging networked technologies can support new modes of interaction, but in order to do so, they require a novel way of approaching learning and teaching that overcomes school culture barriers. For example, similarly to other Web 2.0 tools, wikis introduce a new culture of learning to schools that seems to present challenges to their successful pedagogical integration (Grant, 2009). Accepting this new mode of learning practice assumes that, among others, the notions of collaborative knowledge building, peer critiquing, and editing peer work become the norm rather than the exception. The use of wiki platforms and similar collaborative writing tools online will inevitably need to be accompanied by discussions about peer critiquing and ethical issues such as the copyright of digitally-shared ideas. These conceptual issues mediate the use of the technologies. Ultimately, a new mode of thinking is necessary to support the transformative nature of these technologies (Grant, 2009).

In conclusion, this chapter has provided some examples of emerging web-based learning technologies that can support synchronous and asynchronous collaboration as well as facilitate both reflection-in-action and reflection-on-action. Future advances in technology will enhance student opportunities for collaboration and reflection. For example, collaboration would be further facilitated as ubiquitous computing becomes more common and technology is integrated into smaller, cheaper, and more user-friendly devices. Enhanced participation, capabilities to be involved in dynamic creative processes, such as those afforded by Web 2.0 and immersive participation tools, can sustain student motivation and engagement, support the articulation and externalization of ideas, and make learning more meaningful. Advances in artificial intelligence can allow the personalization of learning, so that targeted support can be provided to address individual or group challenges. At the same time, due to the emerging nature of technologies, there is a need for additional research related to the design of such tools and the ways in which they can be re-purposed for use in educational settings. More research is also needed on the impact of wiki technologies on learning, especially where K-12 education is concerned. Finally, the potential of networked technologies for supporting teachers' ability to provide formative and embedded assessment needs to be examined more closely.

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Chapter 9

Like, Comment, Share: Collaboration and Civic Engagement Within Social Network Sites

Christine Greenhow and Jiahang Li

> Individually, we are one drop. Together, we are an ocean.
>
> —Ryunosuke Satoro

Unlike typical implementations of technology in education, which are dominated by Internet search and retrieval activities with limited peer interaction (Greenhow, Robelia, & Hughes, 2009), the technical and social features of social media, and social network sites (SNSs) especially, provide rich opportunities for collaboration. In particular, such technologies afford social network intensification and building, sharing within and among diverse groups, public or semi-public self-presentation or construction of identity, and opportunities for personal and collective agency within the online-offline community. All of these aspects can be useful in improving teaching and learning practices. Thoughtful adoption of social media may help fulfill the visions presented in a new National Educational Technology Plan (U.S. Department of Education [USDOE], Office of Educational Technology, 2010) that calls for better bridging between students' in-school and out-of-school learning; the creation of relevant, personalized learning experiences; and seamless integration of technologies that mirror students' daily lives and future realities.

In this chapter, we argue that SNSs and social networking applications enable innovative forms of peer collaboration and civic engagement. To this end, we begin by defining key terms and summarizing the research surrounding the use of these technologies in education before presenting exemplars and concluding with recommendations for researchers and educators. Because very few studies have been published

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C. Greenhow (✉)
College of Education, Michigan State University,
East Lansing, MI, USA
e-mail: greenhow@msu.edu

J. Li
College of Education, University of Maryland,
College Park, MD, USA
e-mail: ljh@umd.edu

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within the educational research literature that address learning and teaching with SNSs, we discuss existing research within the larger field of social media and education to contextualize the exemplars presented.

Despite a media storm linking students' use of the popular SNS Facebook (FB) to lower grades (Karpinski, 2009)—claims that have since been disproven (Pasek, More, & Hargittai, 2009)—there is actually little published empirical work in the educational literature regarding the intellectual and social practices young people demonstrate, either in naturally occurring, youth-initiated SNSs, such as FB, or in social networking applications designed for education (Greenhow, 2010, 2011a). Within the interdisciplinary fields of learning sciences and digital media and learning, however, a handful of researchers seek to understand the learning enabled by particular forms of social media, such as SNSs, and to examine the influence of social media features and their attendant social practices on students. These studies have revealed that social media practices can facilitate new forms of collaborative knowledge construction (Cress & Kimmerle, 2008; Greenhow, 2011a; Larusson & Alterman, 2009), communication (Greenhow & Robelia, 2009a), identity work (Greenhow & Robelia, 2009b), social capital (Ellison, Steinfield, & Lampe, 2007; Greenhow & Burton, 2011; Valenzuela, Park, & Kee, 2009), and civic participation in the online-offline community (Greenhow, 2011a; Robelia, Greenhow, & Burton, 2011). Such research suggests the possibilities of educational designs for learning powered by social media as well as the re-visiting of conventional learning theories played out in such contexts.

In this chapter, we focus on peer collaboration and civic engagement rather than these other forms of learning for two reasons: (a) recent standards and policy documents emphasize collaborative knowledge creation and civic participation as essential competencies for students in the twenty-first century (International Society for Technology in Education, 2007; Partnership for 21st Century Skills, 2008), and (b) the socio-technical features of SNSs, especially, seem conducive to helping bring these about, as explained later in the chapter. Moreover, we view the development of collaboration and civic engagement within SNSs and beyond them as potentially synergistic activities. For example, people help forge trusting relationships when they register their interests, preferences, and abilities in semi-public SNSs. Further, individuals may be more likely to work together as they get to know and trust each other, creating ideas and practical strategies that may be applied to solving problems in their local communities. Moreover, cultivating broad social networks provides access to information and opportunities (e.g., volunteering, campaigning) that may be otherwise unavailable. Thus, online collaborations may result in working together on common issues or in demonstrating civic engagement offline.

Furthermore, the chapter explores aspects of learning that occur in youth-initiated SNSs and social networking applications within informal learning environments as well as in formal settings. The difference between the two situations is that an agent (e.g., a teacher, an educational software program, or a learning management system) with a formalized set of objectives (e.g., curriculum standards) directs formal learning, whereas informal learning can be generated with or without certain objectives outside of classrooms (National Science Teachers Association [NSTA], 1999). Current policies emphasize the importance of educational reforms that attend to both settings (USDOE, 2010).

As Internet access, the nature of the Web, and contexts for learning have transformed in the last decade, so too have desired competencies for learners and teachers. These shifts have impacted constructs for learning and instruction, as well as paths for learning sciences research (Greenhow et al., 2009). Internet-connectivity in schools, homes, and neighborhoods has become increasingly pervasive, facilitating expanded sites for learning. Specifically, cultural and technological trends have contributed to young people's adoption of *social media*, a term often used interchangeably with *Web 2.0* to refer to online applications that promote users, their interconnections, and user-generated content (Cormode & Krishnamurthy, 2008). Ninety percent of school-aged youth use the Internet regularly, with over 75 % of adolescents aged 12–17 using social media (DeBell & Chapman, 2006; Lenhart, Arafeh, Smith, & Macgill, 2008). Indeed, use of SNSs is the dominant out-of-school, leisure-time computer-using activity among American teenagers (Rideout, Foehr, & Roberts, 2010).

Examples of social media typically include SNSs like Facebook, MySpace, and Ning as well as media-sharing services. We define a *SNSs* as a web-enabled service through which individuals can maintain existing ties and develop new social ties with people outside their network (Greenhow & Robelia, 2009b). SNSs feature prominent personal profiling, the ability to make one's social connections transparent, and the ability to view and traverse the networks of one's friends (Boyd & Ellison, 2007). Our definition encompasses SNSs used primarily to connect with those one already knows, as well as SNSs used primarily for networking or building one's list of personal contacts. Beyond SNSs, other examples of social media include media-sharing services like YouTube and Flickr, collaborative knowledge development through wikis, and creative works like blogs and microblogging (e.g., Twitter, Blogger).

Next, we draw from nascent research in the learning sciences and digital media and learning fields to illuminate how social media offer new possibilities for peer collaboration and civic engagement within formal and informal learning environments. We focus especially, but not exclusively, on SNSs and social networking applications.

Background

Theoretical Connections: Social Media and Situated Learning Theory

Conceptually, social media seem to embody social constructivist views of knowledge as decentralized, accessible, and co-constructed by and among a broad base of users (Dede, 2007; Greenhow et al., 2009). Situated learning theory (Brown, Collins, & Duguid, 1989; Greeno, 1998) posits that learning is located in contexts and *relationships*—or communities of practice (Wenger, 1998)—and is mediated by artifacts over time (e.g., technologies, language). Situated learning theory emphasizes the importance of individual and group learning within complex social organizations through *agency*, in which individuals and groups are shaped by and actively shape their environments. Peer groups, for instance, can socialize students into certain civic, political, and cultural identities; Witness the rise of social movement activities (e.g., environmentalism, community betterment, human rights groups) among younger generations vs. conventional political activities (e.g., voting) (Torney-Purta, Amadeo, & Andolina, 2010).

Situated learning theorists have examined how the design of learning environments can result in learners improving their capacities for participation in ways that are valued within a community of practice (Greeno, 1998). This theory is particularly relevant to examining collaboration and civic engagement in social media spaces because it suggests that learning addresses *real-life problems* and can occur in contexts that are not necessarily institutional (Zepke, 2005).

At this point, it is important to address what we mean by the terms collaboration and civic engagement. We define *collaboration*, or *collaborative knowledge building*, as shared meaning-making (Stahl, 2006; Stahl, Koschmann, & Suthers, 2006). Collaboration refers to more than just individual learning in groups; it includes "the practices of meaning-making in the context of joint activity" (Stahl et al., 2006, p. 418). Knowledge lives in groups, teams, and social networks and it is an empirically observable activity, as opposed to existing only in the mind. Collaboration provides artifacts, which give evidence and the basis for evaluating knowledge building. Written speech in online discussions; group-authored, dynamic online texts; and peer-to-peer correspondence in response to students' work are all examples of artifacts that we might observe and notice evidence of knowledge being built from interactions.

We use the terms *community engagement* and *civic engagement* (CE) interchangeably to indicate a multi-dimensional construct that includes people's *knowledge* of key concepts and principles, *expression* of ideas, *joining*, and *acting* (Bennett, Freelon, & Wells, 2010; Torney-Purta et al., 2010; Torney-Purta, Lehmann, Oswald, & Schulz, 2001). Thus, our definition of civic engagement necessarily encompasses *participation* in civic, electoral, or political activities typically driven by a sense of duty and respect for authority (e.g., voting, consuming information from authoritative sources, campaigning, petitioning lawmakers).

Social media, with its emphasis on personal profiling, social connections, and peer-to-peer and group communication, would seem to provide fertile ground for the personal and collective agency and the relationship-building that seed productive collaborations and civic engagement over time. "My Profile" features on FB, for instance, engage users in creating their online identity (in text, image, and video forms) and connecting it to the content they create and share within the system. Such connections may facilitate collaboration as people want to know and reciprocate with those who share not only their ideas but personal information. Many SNSs also include multiple channels for interpersonal feedback and peer acceptance. Within FB, "Wall" features allow users to (a) critique or build on others ideas by adding links to each other's posts; (b) contribute comments, video, or graphic images; and (c) register their agreement or support for an idea (e.g., thumbs up or down). Moreover, SNSs like FB may satisfy users' informational needs, a critical element for strengthening relationships and promoting collective action (Valenzuela et al., 2009). The "News Feed" feature, for example, which appears on each FB user's homepage, provides the latest updates about the activities and contributions of one's contacts. Staying "in-the-know" about what is going on at the community level may help reinforce one's sense of belonging in the community and aid in spreading awareness of issues, problems, and ways to get involved.

Although the aforementioned features of SNSs seem to lend themselves to enabling productive collaboration and civic engagement, research is needed to determine whether this is indeed the case and the ways in which these goals can be accomplished. To that end, we briefly summarize research that conceptualizes and reports on how SNSs, or social media contexts generally, offer possibilities for collaboration and civic engagement within formal and informal learning environments.

Collaboration and Social Media

Researchers have explored how emerging technologies enable collaboration among participants in various settings (Cress & Kimmerle, 2008; Larusson & Alterman, 2009; Zhang, Scardamalia, Reeve, & Messina, 2009). Some researchers have focused on collaborative knowledge building in online social networks generally (as opposed to SNSs). For instance, in studying elementary school students within a formal classroom setting, Zhang et al. (2009) found that social networks within Knowledge Forum (http://www.knowledgeforum.com) provided opportunities for students to connect to a broader network of other members and their ideas than they might have otherwise. Connecting to this broader network facilitated high-level collective responsibility for the learning of the group and dynamic knowledge advancement over time through flexible, opportunistic collaborations. Using online discussions increased the possibility of diverse spontaneous inquiries, flexible participation from group members, and transparency. In particular, participants could see ideas taken up and modified by the group; this in turn helped students grasp an overarching vision of the changing status of their community knowledge and the interactions taking place at the community level.

Other researchers have investigated whether a particular form of social media—wikis—could support collaborative knowledge building. For instance, Larusson and Alterman (2009) examined college students' use of the WikiDesignPlatform to collaborate on activities that required varying degrees of coordination, such as those asking students to share a common goal and produce a single outcome or those stipulating only some common ground but no shared outcome. They concluded that the wiki could simplify the task of coordinating collaborative work online and could scaffold and structure students' collaboration in both types of activities (see also Chap. 7, section "Exemplars" and Chap. 8, section "Exemplar 2: Wikis in Support of Collaboration and Reflection-on-Action").

Similarly, Cress and Kimmerle (2008) examined collaborative knowledge building in Wikipedia, a wiki environment that served as a context for informal learning.

In documenting collaboration in Wikipedia and its underlying mechanisms, Cress and Kimmerle argued that Wiki participants *externalized* their knowledge by placing it into the public sphere and by building on others' information in the wiki article (e.g., through posting content, critiquing, deleting, and revising others' content). Participants also *internalized* information by integrating entry revisions into their own understanding. Identifying the processes employed at different stages of collaboration within wikis and other social media may increase our understanding of the relationships between social and cognitive realms (Cress & Kimmerle, 2008).

Although these studies have examined social media other than SNSs, the findings suggest that collaboration and coordination among a range of participants may be facilitated by social media embodying the following features: (a) a non-hierarchical structure where learners have ownership of and can contribute to a public or semi-public space; (b) the ability to asynchronously co-produce content; (c) automatic publishing capabilities; (d) the ability to adapt the layout or functionality of the environment; and (e) the ability to enable geographically distributed, opportunistic, flexible, and dynamic social arrangements rather than centralized or fixed arrangements because these may help generate a diversity of ideas (Cress & Kimmerle, 2008; Larusson & Alterman, 2009; Zhang et al., 2009). Most SNSs contain all five of these elements.

Civic Engagement and Social Media

A handful of scholars have sought to identify and document the relationship between young people's participation in social media, such as SNSs, and their civic engagement (e.g., Byrne, 2007; Greenhow, 2011b; Hull & Stornaiuolo, 2010; Park, Kee, & Valenzuela, 2009; Robelia et al., 2011; Valenzuela et al., 2009). For instance, Byrne (2007) examined community life in BlackPlanet, a SNS that features user-driven discussion forums on topics ranging from entertainment to race-related issues. The site also features links to news articles and response sections, chat rooms, and subscription groups. Analyzing online discussion data, Byrne found that the site fostered components of civic engagement, such as expression of ideas and joining, but not personal agency or collective action.

In contrast, Valenzuela et al. (2009) found positive relationships between the intensity of general FB use among college students and their reported level of civic engagement and political participation. They suggested that students who used FB Groups more actively and purposefully were more inclined to participate in civic and political activities offline (Park et al., 2009). The FB Groups application displays each individual's group memberships as well as groups their "friends" have joined. Students who belong to a civic or political group within FB can receive mobilizing information that may not be available elsewhere and can learn about opportunities to engage in civic, political, and electoral activities. Valenzuela et al. (2009) argued that increased participation in online FB groups helps to build trusting relationships among members and potentially increase levels of civic engagement offline over time.

Examining civic engagement in a formal learning environment, Hull and Stornaiuolo (2010) are exploring whether or not an international SNS can help middle and high school students develop local and global citizenship. Using Space2Cre8 (http://www.space2cre8.com/), a password-protected site available to 7–12th grade students in four countries, the students can collaborate with their local peers and international friends to create and exchange ideas and digital artifacts. Although Hull and Stornaiuolo's content analysis of adolescents' contributions is ongoing, they argue that SNSs may help bridge school and non-school activities to foster increased community engagement.

Such research efforts suggest that SNSs may facilitate learners' civic engagement. Features unique to SNSs may foster norms of reciprocity and trust as users feel more inclined to express their ideas in spaces with prominent personal profiling; join causes they learn about through their "friend" networks; keep updated via user-centered news feeds; and increase their knowledge of other members' civic, political, or electoral activities, influencing their own participation.

Exemplars

Next we provide two exemplars of what promising use of SNSs look like in practice: one for fostering collaboration and the other for promoting civic engagement. We describe the specific socio-technical space, the forms of collaboration or civic engagement emerging therein, the mechanisms that seem to bring these about, and how such spaces may be used by teachers, students, and youth workers. Each exemplar is drawn from research projects currently underway that focus on investigating the potential of these tools for developing new competencies, learning approaches, and practices in the digital age.

Exemplar 1: Collaboration with a Social Networking Application

Remix World (RW) (http://digitalyouthnetwork.org/6-online/pages/19-remix-world) is a SNS created with the SNS-generating tool, Ning.com, for the Digital Youth Network (DYN) (http://digitalyouthnetwork.org/). The DYN consists of three charter schools in Chicago, IL, each with a technology and media arts program. Students from grades 6 through 12 participate in DYN programs. DYN's goals are: (a) to provide learners with new media literacy experiences, (b) allow them to create high quality new media products of their own choosing as well as through the DYN curricular model, and (c) provide public spaces to highlight their accomplishments. Furthermore, DYN seeks to bridge in-school and out-of-school learning to more accurately reflect and support a learning ecology across school, home, and communities (Barron, 2006).

RW is distinguished from other online learning environments in that it embodies FB-like visual features and practices, tapping into students' prior experiences with similar sites. It incorporates references to popular culture and modes of representation with which students are already familiar, such as online media-sharing. DYN students are encouraged to join, set up a personal profile, post original work, comment on media and artifacts, identify and connect with other users in the DYN network, and view and critique their peers' work. Mentors serve as media arts program instructors and curriculum developers. They post original work, provide feedback, and try to model and scaffold participation in the site. RW offers a semi-public space for youth and adults to interact around issues of interest to students, reflect on those issues, ask questions, socialize, discuss, and critique (Zywica, Richards, & Gomez, 2011). A data tracking system built into RW allows the design team to track the number of users, types of activities, and usage patterns at the individual and community level.

Although analysis of RW is ongoing, researchers are studying the complexity of student collaborations and how to structure them in such spaces. Preliminary case study results suggest that mentor and peer feedback play an integral role in students' motivation to participate in RW. Participants reported that RW supported the creation and sharing of work among peers or between peers and mentors because it enabled feedback using multiple modes of communication (visual, auditory, and text-based modes). Participants could use the different modes to register their support and to construct meaning in the discussion forums (Richards & Gomez, 2010; Zywica et al., 2011). Students and mentors worked through problems and controversies, engaging in meaningful peer-to-peer and peer-mentor dialogue and support that may not have occurred in the classroom (Zywica et al.). Moreover, users felt that working in RW helped them develop *public identities* within a community context (Richards & Gomez, 2010). RW acted as a bridging space across previously disparate communities: media arts instructors and classes and students' informal media-sharing among peers outside of school. These opportunities have resulted in students engaging in new media literacy practices outside of school that are related to the in-school curriculum, a major goal of the project (Richards & Gomez).

Mechanisms that seem conducive to fostering trust and shared meaning-making in RW included users' ability to (a) communicate in various media; (b) share a personal profile within a system that convenes peers and adults from various social networks; (c) analyze, critique, and contribute via online discussion; and (d) work in an integrative team model that enables mentors to make intentional linkages between online and offline spaces (e.g., DYN classes and the afterschool program).

Exemplar 2: Civic Engagement with a Social Networking Application

The second exemplar, Hot Dish (HD), is an open-source social networking application designed and implemented within FB as a site for informal learning. The objective in designing the site was to engage young people (ages 16–24) in information-sharing, collaborative knowledge building, and civic engagement around environmental science and climate change issues. A research project involving HD was funded in Fall 2008 by a grant from the John S. and James L. Knight Foundation and enabled the first author, the principal investigator, to collaborate with the social software developer NewsCloud.

HD offered a customized user interface that looked quite different from generic FB pages or FB Group pages. The application facilitated multiple channels for users to get to know one another and to share their knowledge and information about climate change issues and action strategies. Features included the ability to post original story entries (in text, video, and images) or circulate articles from online sources. Members could read an article's overview or read the full article. Users could curate and rank posted entries by writing short summaries, voting them up, commenting on entries, or sharing them within the HD network or other online venues. HD users could also tweet and chat about stories they found most interesting.

HD participants created a self-profile in the "My Profile" feature. Similar to FB (the parent site), members portrayed their background, interests, and ideas through online photos, bio, blog, and data-reporting features that showcased the artifacts and activities they had contributed. Using FB and Google analytics, the HD application automatically tracked participants' use of these features so that site usage statistics could be generated (e.g., number of users, types of activities, and usage patterns) and analyzed at the individual and community levels. HD embodied the situated learning theory as users learned in a social context in which they chose to participate; it offered a platform where individuals with an interest in climate change issues could read relevant articles, share environmental knowledge, and debate strategies.

Learning scientists (Zhang et al., 2009), environmental scholars (Heimlich & Ardoin, 2008), and civic engagement researchers (Bennett et al., 2010; Torney-Purta et al., 2010) stress the importance of developing knowledge, critical evaluation, interpretation, and self-expression within diverse and dynamic networks of people and ideas. They also stress the importance of providing learners with opportunities to join together and act on knowledge and attitudes. The HD application sought to embody these principles by engaging users in pro-environmental civic and political activities in two ways: by having them join an Action Team and by requiring that they take part in Action Team challenges. Challenges provided incentives to learn new personal eco-friendly action strategies as well as opportunities to practice them. They required actions online or offline in the local community. Online challenges included posting a story, voting on a story, commenting, or inviting friends to join the site. Offline challenges included civic or political activities such as starting a recycling program, volunteering for an environmental organization, writing a letter to the editor, petitioning a lawmaker, or attending an environmental event. Offline challenge completion required uploading documentation (text, video, images) for evaluation by the project partners.

Thus, the HD site was designed to implement traditional theories of civic engagement that emphasize civic, electoral, or political activities driven by duty and respect for authority while embracing innovative forms of civic participation driven by personal passions and user-generated content. Bennett et al. (2010) argue that civic participation today necessarily extends beyond institutions to consumer politics and global activism and can blur the lines between consuming information and producing media to share.

Although findings related to collaborative knowledge building within HD are forthcoming, data collected from an online survey, site usage statistics, focus groups, and interviews revealed that HD users reported above average knowledge of climate change science and an increase in civic and political activities related to environmentalism during their involvement with the FB application. Site usage statistics show that learners completed approximately 2,000 local, offline challenges over a 2-month period and 20,409 total challenges (online and offline). Focus groups indicated that peer role modeling through interaction on the site motivated these pro-environmental activities.

Mechanisms that facilitated learners' civic engagement were those that showcased learners' completion of Action Team challenges, potentially motivating peers in the network to similarly complete global or local civic activities they would not have performed otherwise. These features included automatically published *comments* and a *vote up* option that registered peer approval. Community-building features, such as *share* and *invite friends*, provided recognition. The public documentation of challenge completions also contributed to a user's status in the community; those most engaging in action challenges earned the title of "Town-crier" or "Climate Czar" and users' activities appeared publicly in their My Profile, which dynamically updated with their increasing involvement. Such mechanisms kept members learning about how other members were taking action on the issues and enabled them to register their feedback, support, or demonstrate similar contributions (see Chap. 17, sections "Exemplars of Sharing" and "Exemplars of Reflecting," for instances of how commenting, sharing, and reflecting in the Scratch online community contributed to the status children held within that community and to improvements in artifacts they created).

Conclusions and Next Steps

Advice for Educators

For educators who are interested in using social media, such as SNSs, in their teaching or who seek to understand how SNSs may help promote learning (e.g., collaboration and civic engagement), we offer several suggestions. Drawing on these examples, we address: (a) how SNSs might be used across formal and informal learning settings; (b) what pedagogical models seem most promising for successful integration and with what roles for teachers, learners, and other adults; and (c) the instructional challenges that might be expected and need to be overcome. First, SNSs and networking applications like Hot Dish and Remix World may offer useful bridging spaces between classrooms, afterschool clubs, and students' out-of-school interest-driven pursuits. They may be generated via low cost SNS-generation tools or open source, social networking application templates, and benefit key stakeholders—teachers, students, library media specialists, youth program workers, and evaluators—in several ways. For instance, the personal and multimedia profiling features that such technologies afford may assist educators in getting to know their learners' interests, talents, and aspirations. Teachers can use such sites to learn about their students through explorations of their personal pages and comments: "This can be the springboard for inquiry-oriented projects of interest to students and for linking traditional disciplinary material to students' background knowledge and experience" (Zywica et al., 2011, p. 113). Such sites may also assist learners in getting to know one another, which could further stimulate collaboration and collective action.

Similarly, SNSs may be used to engage and connect students with debates about current political, economic, and social issues surrounding a particular topic of study (e.g., global warming, presidential politics, human rights), thereby helping educators update their instruction, connect students to a broader network of ideas and expertise, and provide opportunities to apply what they are learning in local or global communities. As demonstrated in both exemplars, teachers, mentors, or project team members can use such spaces to provide timely and multimedia feedback to students on their evolving practices (e.g., media arts practices or generation of problem-solving and action strategies) and if desired, link them to formal learning objectives related to curriculum areas such as digital literacies, scientific inquiry, educational technology standards, or twenty-first century skills.

Such spaces benefit students by helping them co-create and design their own online spaces with their particular social agendas, while receiving support through opportunistic, flexible collaborations with members of their school and other communities. Thus, sites, such as RW and HD, have the potential to bridge in-school content and formalized opportunities for collaborative knowledge building and civic engagement with student-relevant out-of-school knowledge and practices. In addition, stakeholders could use automated data-gathering features of SNSs and networking applications to assess the extent to which students are learning in the space and how (e.g., which features are most utilized by which groups of users, how peers influence each other, and how ideas or actions are developed and spread within the network). These insights could be fed back into the re-design of the application and instructional strategies.

Second, in using social media, such as SNSs and social networking applications, educators who embrace or value situated learning theory and teaching in a social constructivist manner may be especially assisted in implementing their preferred pedagogical style. Briefly, constructivist models advocate a learner-centered approach where learning and instruction are *facilitated* by the teacher rather than *transmitted* as in a traditional lecture-oriented, teacher-centered classroom. Learners' background, expertise, and beliefs are important to understand and build on because they affect the learning or knowledge that is developed; experience and situations that have direct relevance and applicability to the learner's life and interests are those that provide the best opportunities for learning (Brown & Duguid, 2002). Knowledge becomes meaningful through interpretation and application in a community where knowledge is shared. Thus, this approach encourages flexible role-taking and team effort where teachers, students, youth workers, and other adults may work across settings to provide guidance and where students (and others) are encouraged to express their interests, exercise creativity, generate ideas, collaborate, and apply what they know to realistic, complex problems.

Personal profiling, multimedia communication affordances, multiple feedback channels, user news feeds, non-hierarchical structure, spontaneous publishing and other social network diversification, intensification, and expansion features are all aspects of social media that may help facilitate this pedagogical model. They do so by: (a) illuminating and connecting the personal interests, experiences, contributions, and communities of various members; (b) pulling in information or expertise beyond the formal, pre-conceived learning network; and (c) applying the knowledge developed to real issues or problems.

Third, innovation, of course, is not without challenges. Obstacles that educators will need to overcome when implementing SNSs across formal and informal learning settings are: (a) lack of administrative vision, planning, and support; (b) public ambivalence about online privacy and security; (c) school culture that prevents team approaches to instructional planning and evaluation efforts; (d) students' naïve or inchoate understandings of online collaboration, responsible, and ethical internet use; and (e) a current testing climate that does not emphasize digital literacies, twenty-first century skills, and other competencies discussed above and implicated in the new National Educational Technology Plan.

In order to overcome such challenges, teachers can initiate small-scale, needs-driven, social media-enabled instructional collaborations with library media specialists, who typically have expertise in technology integration and in teaching about responsible and ethical use of information technologies. They may also involve youth workers or other adults to meaningfully extend instruction into the community around students' hobbies and interests. Frequently, such instruction will involve students using social media beyond the school day, especially if this media is largely blocked in school. Further, they may establish learning objectives tied to standards that are also based on learners' needs and interests. Such collaborative instruction would allow students to demonstrate both online and offline performance. Finally, teachers may collect data on whether or not students' use of social media facilitates the desired outcomes and how. They can share those results with key administrators, teaching staff, and public allies to catalyze discussion about how the school's Internet use policies, vision, and support might facilitate future social media integration to achieve desired outcomes.

Research Needed

Currently, two-thirds of the world's Internet population use SNSs, as they have become a fundamental part of the global online experience (Nielson Wire, 2009). As educational researchers and learning scientists interested in emerging technologies for learning, we have a responsibility to inform the current public debate on social media, learning, and education. Several major research topics that will drive research in the next decade have been alluded to in this chapter. The studies here notwithstanding, as scholars and learning scientists, we still lack an accumulation of research and design work that examines various forms of learning enabled by different types of social media, like SNSs and social networking applications, in informal learning settings and in classrooms especially (for a more complete discussion see Greenhow, 2011a; Greenhow et al., 2009).

A promising approach to conducting this research is to examine learning with social media that aligns with those digital literacies, information literacies, national educational technology competencies, and twenty-first century skills increasingly touted but under-taught and under-tested in today's schools (e.g., collaboration, civic engagement, creativity, communication in various media, etc.). Furthermore, we might examine students' intellectual and social practices in popular youth-initiated social media spaces and consider how they align, fail to align, or suggest competencies that should be valued and taught in school (e.g., managing one's online identity, crafting and promoting our online portfolio, forming strategic networks, and learning with collaborative and media-sharing tools). We ought to attend not only to different groups of students (the youth population is not necessarily unified in its access or use of social media or technology skills), but also to different socio-technical spaces and how varying spaces afford or impede the outcomes we seek. In considering the relationship between in-school and out-of-school learning and the use of social media as bridging spaces, we might work to trace how young people's involvement and development in SNSs intersect with or influence their involvement and development in the school community, and vice versa. Finally, from an accumulation of research efforts in these areas, we ought to formulate more evidence-based guidelines for implementing SNSs and networking applications in instructional settings and help policy-makers and administrators better address and navigate the public's concerns over privacy, safety, and educational outcomes.

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Part III

Technologies that Support Anytime, Anyplace Learning

Chapter 10
The Role of One-to-One Computing in the Education of at-Risk High-School Students

Chrystalla Mouza and Albert Cavalier

In the mid 1990s, schools began implementing programs to bring mobile technology into the classroom, primarily through the use of laptops that enabled a one-to-one student-to-computer ratio. In the U.S., beginning with Microsoft and Toshiba's Anytime Anywhere/Notebooks for Schools project, Apple's One-to-One Project, and IBM's Reinventing Education Project, implementation of laptop programs has become increasingly popular. Although such programs initially were implemented only in select classrooms at the individual school level, the declining unit costs and increased availability of wireless connectivity has made it possible to implement such initiatives on a broad scale (Penuel, 2006). Following Maine's lead in 2002 to implement a statewide laptop initiative, for example, other states have also helped equip hundreds of thousands of students with laptop computers through programs like *Classrooms for the Future* by the Pennsylvania Department of Education, *Freedom to Learn* by the Michigan Department of Education, *Technology Immersion Project* by the Texas Education Agency, and *Leveraging Laptops* by the Florida Department of Education to name only a few. Large districts, such as Henrico County in Virginia and Cobb County in Georgia, also have provided laptops to all their middle and high-school students. The most successful of these initiatives allow students to carry their laptops back and forth from school to home, thereby offering the possibility of 24/7 access to technology.

Laptop programs have also begun gaining attention outside the U.S., particularly in developing countries where there is public demand for new ways of improving educational systems (Severin & Capota, 2011). Many of these countries, which lack substantial financial resources, take advantage of the low-cost laptop designed by the One Laptop Per Child (OLPC) Initiative at the Massachusetts Institute of Technology Media Lab and Intel (Severin & Capota). Beyond the desire to improve the quality of education through new practices that integrate technology, laptop

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C. Mouza (✉) • A. Cavalier
School of Education, University of Delaware,Willard Hall 219 D, 19716, Newark, USA
e-mail: cmouza@udel.edu; cavalier@udel.edu

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programs in developing countries seek to strengthen the economic competitiveness of their region by improving students' technology and workforce skills and by creating more equitable access to technology (Severin & Capota; Zucker & Light, 2009).

Despite the rapid growth of laptop initiatives around the globe, opinions on whether such programs are worth the investment are mixed, fueled largely by the lack of rigorous empirical investigations of their efficacy (Penuel, 2006). Much of what we know about laptop initiatives to date comes from program evaluations that seek to investigate the extent to which laptops are utilized in the classroom and their impact on student learning experiences (e.g., Silvernail, 2005). Few studies have looked at changes in the learning environment or identified instructional practices that utilize laptops in ways that illustrate what we know about how people learn (e.g., Dunleavy, Dexter, & Heinecket, 2007). Even fewer studies have looked at the ways in which laptop programs can benefit academically challenged student populations, such as career and technical education students or those with learning and other types of disabilities (e.g., Mouza, Cavalier, & Nadolny, 2008; Unger & Cook, 2007).

Our purpose in this chapter is twofold: First, we summarize the evidence base on the ways in which laptops can change traditional learning environments in K-12 schools. Second, we provide examples that illustrate how teachers and students can use laptops to alter teaching and learning processes, transform the quality of instruction, and improve student outcomes. These examples are generated from a 3-year longitudinal investigation focusing on the design, implementation, and outcomes of a laptop initiative for students with learning disabilities in a career and technical education high school in the U.S. We analyze and discuss these examples using learning sciences principles on the design of effective learning environments (Bransford, Brown, & Cocking, 2000).

Background

In this section we summarize what is known about the impact of laptop programs on four distinct areas: (a) student technological literacy, (b) technological equity and digital divide, (c) quality of instruction, and (d) student academic achievement. According to Penuel (2006), those are the four outcomes typically desired by proponents of laptop initiatives.

Laptops and Student Technological Literacy

Broadly defined, *technological literacy* is the "capability to use, understand, and evaluate technology as well as to apply technological concepts and processes to solve problems and reach one's goals" (WestEd, 2009, p. v). Although the current generation of students is referred to as *digital natives* to indicate the technology-rich environment in which they grow up (Prensky, 2001), research indicates that their sophistication and understanding of technology varies significantly. Thus, it is important that schools and teachers provide pedagogical interventions that help all students acquire a basic familiarity with technology and think critically about technology issues (Pearson & Young, 2002).

The need to develop technology skills while in school is particularly important for students with learning and other types of disabilities. According to Hasselbring and Glaser (2000), these students often need more explicit instruction on how to access or utilize various digital tools compared to their non-disabled peers who often can learn through experimentation or trial and error. Nevertheless, evidence indicates that individuals with disabilities often do not have access to or utilize computers to the same extent as their non-disabled peers. Helping these students acquire sophisticated technology skills is critical as they exit high school and pursue employment and independent learning opportunities (Hasselbring & Glaser).

Results from research and evaluation studies on laptop initiatives consistently demonstrate positive outcomes in student technological literacy. In a 4-year longitudinal study on the evolution of a laptop initiative, Lei (2010) found that in the first 2 years student technological proficiency significantly increased. A number of comparison studies also demonstrated greater levels of technological literacy among students in laptop programs compared to non-laptop, including knowledge of hardware and operating systems, commonly used productivity tools, skills in using the Internet, and knowledge of basic computer security (e.g., Lowther, Ross, & Morrison, 2003; Schaumburg, 2001). Similarly, a longitudinal study in Texas found that economically advantaged and disadvantaged students in laptop schools became significantly more technology proficient than their peers in control schools. More importantly, economically disadvantaged students in laptop schools reached proficiency levels that matched the skills of advantaged control students (Shapley, Sheehan, Maloney, & Caranikas-Walker, 2009).

Laptops and Digital Divide

From a quantitative standpoint, the digital divide refers to the gap between those individuals and communities that have and those that do not have access to information technology. From a qualitative standpoint, it refers to a disparity in the way in which technology is used that is more cultural in nature (OECD, 2010).

In the U.S., existing data indicate that significant gaps in Internet usage still exist among certain segments of the population. According to a recent report by the U.S. Department of Commerce (2010), while over 80 million households have adopted broadband Internet access, 38 million do not have such connectivity. Further, a disproportionate percentage of certain minority groups, people with low incomes, less education, disabilities, and seniors continue to lack access to broadband connectivity. On a global landscape, developing countries continue to trail behind developed countries with respect to reliable and broadband Internet access, while large disparities also exist among developing countries themselves (Severin & Capota, 2011).

In the U.S., these findings in home access to technology and broadband connectivity parallel school access to technology. Wells and Lewis (2006), for instance, found that schools with lower levels of minority enrollment still have lower ratios of students to computers than schools with higher minority enrollment. Further, in low-socioeconomic status (SES) school teachers are less likely to receive professional development or have access to full-time technical support, practices that are associated with more widespread and rigorous use of technology (Warschauer, Knobel, & Stone, 2004). Finally, in low-SES schools, students are more likely to use computers for remedial literacy and numeracy rather than for research, analysis, and higher-order thinking tasks (Warschauer et al., 2004; Wenglinsky, 1998).

Providing every student with a laptop that can be taken home can have a tremendous impact on students who are currently left out of the world of technology. Nevertheless, few studies have explicitly investigated the ways in which laptop initiatives help bridge the digital divide (e.g., Gravelle, 2003). Evidence from the *Maine Laptop Technology Initiative* (MLTI), for example, shows that laptop computers enabled equitable access to technology and the Internet for higher poverty schools and students both in and out of school. Further, access to laptop computers helped students acquire skills, knowledge, and abilities needed to use information, the Internet, and other technologies (Gravelle, 2003). In another study, Mouza (2008) looked at the ways in which laptops can serve as vehicles for bridging the digital divide and providing low-income minority students with enriched learning experiences. Findings indicated that in the hands of well-prepared teachers who valued the use of technology, laptops enabled disadvantaged students to engage in powerful learning experiences that included written expression, preparation of multimedia presentations for an audience, and data analysis and interpretation.

The OLPC initiative is also designed to empower disadvantaged student populations around the world by providing each student with a low-cost connected laptop that they can use around the clock. According to Severin and Capota (2011), 24/7 access to laptop computers can open new opportunities for participation, knowledge, and communication for students and their families living in poverty or isolation, thus creating more equitable social norms.

Transforming the Quality of Instruction

A number of researchers have argued that providing students with networked laptop computers has the potential to transform learning environments. Zucker (2007), for example, writes:

> 1:1 computing is not simply a way of integrating technology into education (*school as it is*, in Seymour Papert's words), but has the potential to change education (*school as it can be*) including what students learn (such as their use of more and different reference materials), with whom they interact about their learning (such as greater interaction with peers), and the products they generate (including different media)… (p. 153).

In order for laptop initiatives to reach this potential, however, teachers often need to alter their pedagogy. Current research consistently indicates that, in conjunction with the use of technology over time, teachers do change their classroom practices, often adopting more constructivist pedagogical approaches that utilize authentic project-oriented methods, inquiry-based activities, and more interdisciplinary approaches that value cooperative learning (e.g., Dawson, Cavanaugh, & Ritzhaupt, 2008; Donovan, Green, & Hartley, 2010; Mouza, 2008). Dawson et al. (2008), for example, found that the infusion of laptop computing accompanied by professional development had a positive impact on teaching practices in at least three ways: increased student-centered teaching, increased tool-based teaching, and increased amounts of meaningful uses of technology. Mouza (2008) also found that in the context of a low-income minority school, laptop computers were used to create rich learning environments that facilitated problem-solving and knowledge construction rather than recitation or drill and practice. Similarly, researchers studying *Project Hiller*, a laptop initiative for urban high-school students, found that the number of teachers who reported using long-term projects increased and that this was associated with the increased occurrence and improved quality of interactions between teachers and students participating in the program (Light, McDermott, & Honey, 2002).

Although these results are promising, other researchers have found that the introduction of laptop computers does not always prompt teachers to implement constructivist instruction. Windschitl and Sahl (2002), for instance, found that the mere availability of laptops did not compel teachers to make extensive use of technology or alter their pedagogy. Rather, laptops served as catalysts that enabled teachers who experienced previous dissatisfaction with traditional approaches to transform their classrooms through collaborative and project-based learning.

Laptops and Student Academic Achievement

Although the ultimate goal of laptop programs is to improve academic achievement, few rigorous studies exist that demonstrate the positive impact of those programs on academic outcomes (Penuel, 2006). The majority of studies examining student outcomes typically report on academic dispositions such as motivation, engagement, and attitudes towards technology. Fewer studies examine test scores or other measures of learning in academic content areas (e.g., Russell, Bebell, & Higgins, 2004).

Existing research focusing on academic dispositions indicates that use of laptops can foster student responsibility and autonomy in relationship to technology and learning, thereby leading to increased motivation and greater academic aspirations (Light et al., 2002; Zucker & McGhee, 2005). Silvernail and Lane (2004), for example, found that the majority of students in the MLTI agreed that laptops had made school more interesting and helped them complete their work more quickly. In her study with low-income elementary students, Mouza (2008) also found that use of laptops increased student motivation and persistence in doing school work, facilitated increased interactions with peers and teachers, and empowered students by fostering confidence in their academic abilities.

In addition to studies on academic dispositions, some research reports further benefits from laptop usage, such as a decrease in absentee rates, school-wide discipline problems, and number of discipline-related letters sent home (e.g., Intel Inc., 2008; Shapley et al., 2009). Taken together, these findings are important given the high dropout rates in secondary education and the strong correlation between engagement and academic achievement (Fredericks, Blumenfeld, & Paris, 2004; Zucker & Light, 2009).

In a study examining specifically the experiences of special education teachers and students participating in the MLTI, researchers found that use of laptop computers improved the engagement of students with disabilities, increased their motivation and ability to work independently, and improved their class preparation. Further, teachers and parents indicated that laptops increased students' personal organization (Harris & Smith, 2004).

Studies examining academic outcomes report mixed results on the overall impact of laptops on student achievement, but consistently report positive academic gains in student writing. Jeroski (2003), for example, found that the percentage of students who produced writing samples that met or exceeded writing performance standards for their grade level significantly increased. Similarly, Lowther et al. (2003) reported substantial increases in writing and critical thinking achievement among students who used laptop computers during problem-based lessons that emphasized critical examination of authentic issues, as well as research and writing skills. A study conducted with participants in the MLTI also indicated that students who used their laptops extensively obtained higher writing scores than those who did not (Silvernail & Gritter, 2007). The same study noted that students became better writers in general, not just better writers while using their laptops. Finally, a more recent study found that after 2 years, laptop students outperformed non-laptop students on changes in the English language arts total score on a standardized test and on the two subtests that correspond to frequent laptop use, such as writing strategies and literary response and analysis (Suhr, Hernandez, Grimes, & Warschauer, 2010).

Other studies, however, failed to document statistically significant effects on standardized assessments despite rigorous and longitudinal research designs. A longitudinal study in Texas, for example, found positive impacts of laptops on technology proficiency and peer interactions in small group activities, but no significant impact on students' test scores in reading and writing and only a weak impact in mathematics (Shapley et al., 2009). While these results are discouraging, it is important to keep in mind that it takes time for laptops to positively impact test scores and that standardized assessments are not clearly aligned with the breadth of skills (e.g., inquiry and problem-solving) that students acquire through their participation in laptop programs (Grimes & Warschauer, 2008; Silvernail, 2005).

Exemplars

In this section, we provide examples of how access to laptop computers can create new learning environments for students who have traditionally struggled academically. In particular, we discuss how ubiquitous access to laptop computers can bolster student technological literacy, transform the quality of instruction, and enhance student learning outcomes. These examples are drawn from a 3-year longitudinal study that examined the design, implementation, and outcomes of a laptop initiative in a career and technical education high school, in which many of the students had identified learning and other types of disabilities. In the study, quantitative and qualitative data were collected that included teacher and student surveys, classroom observations, teacher interviews, student focus groups, and document analyses. For the purpose of this chapter, we focus on the qualitative data.

Participants in this laptop initiative included ten teachers, seven of whom were designated as special education teachers in a variety of content areas. In the first year, 62 students in grades 9–12 were given laptop computers. About half of the students were special education students. During the second and third year of the program, all students except those who graduated kept their laptops. Additional laptops were distributed only to incoming special education students. This policy reduced the number of participants in years 2 and 3 to approximately 40 students.

Exemplar 1: Laptops and Technological Literacy

As noted in the background literature, the need to develop technological literacy in school is particularly important for individuals with learning and other types of disabilities who often do not acquire such skills spontaneously. These skills should be taught explicitly to students with disabilities much like reading, writing, and mathematics skills (Mastropieri & Scruggs, 2010; Salend, 2010). Interviews conducted with teachers indicated that many students participating in this laptop program were initially lacking basic technology skills and confidence in their abilities to use technology. A mathematics teacher explained:

> Initially, I was trying to integrate the laptop, but I recognized that some students were very reluctant to work on their computers. I do not want to say they had a phobia, but they were definitely reluctant. Even to the point where some students asked to handwrite documents instead of using a word processor. And I was adamant about not allowing that, because I know when they graduate at the end of the year and go out in the workplace, they will have to use a computer one way or another. So if they use it in the classroom, at least they will not be totally afraid of it.

Access to laptop computers made it feasible for teachers to integrate a range of online and productivity tools across a variety of content areas. Those practices enabled students to increase their technological capabilities and confidence with regard to technology. A social studies teacher described the challenge of helping all students become more confident technology users and shared some of her strategies. She explained:

> There are some students who are fairly savvy with the computer and they have a lot of resources on their laptops. But many of our students do not know how to use their laptops effectively. As a teacher, I want to focus on content rather than helping students learn essential technical skills, but I still have to do so. As a result, I start at the beginning of the year with some ice-breaker activities that involve using presentation software, such as Microsoft PowerPoint. I keep the content simple until they become more comfortable with the computers.

As students became more comfortable with technology, the focus shifted more on content, and the complexity of the assignments increased in terms of technological sophistication. Discussing students' improved sophistication with technology, another social studies teacher noted:

> The first PowerPoint presentations some students completed were two or three slides with some basic text. Their latest work is more sophisticated; it includes a lot more information, including graphics and other media forms. Basically, my students can now pick up any topic they want, research it, put together their findings, and present it in various interactive formats. Further, the number of technical issues coming up, like "my computer does not work" or "my battery is down" has definitely diminished.

To bolster technological proficiency among his students, the teacher promoted peer sharing and collaboration. On many occasions the teacher asked students to share technology tips and strategies with their peers, such as how to insert a picture found on the Internet or a video clip in a multimedia presentation. Further, he allowed students to move freely in class in order to help their peers with particular technology tasks. As the teacher noted, the special education students were very willing to work with one another. Access to laptops increasingly facilitated learning and collaboration among students, even those who were not traditionally looked upon for help. In fact, in one of our visits, we observed a student with identified learning and physical disabilities being called upon to provide technical help to a peer belonging in the "popular" crowd of students.

Students themselves also commented positively on the ways in which access to laptops enhanced their technological competence. A student with cerebral palsy, for example, who had difficulty using paper and pencil noted: "I feel good about my skills; since I deal with computers every day, the laptop helps me be more knowledgeable about different programs." Other students also commented on how access to laptop computers enhanced their typing skills, their ability to take notes, and their facility with online research. Some students whose vocational area was Computer Information Systems, however, felt that teachers viewed the laptop in the wrong way when focusing simply on software use. In one of the focus groups, they explained:

Dave: The problem is that most teachers look at the laptops in the wrong way. They are viewing the laptops simply as tools to run the software. They are not looking at them as platforms for experimentation and learning.
Ian: It is a very good learning experience.
Dave: The teachers view it as a tool, not as a laboratory.
Ian: They do not feel that students, other than those in a few shops, such as Computer Science or Engine Systems Technology, can learn anything from it. The administration thinks that the laptop is just a tool that replaces paper and pencil. But this is wrong, totally wrong. This thing [laptop] is a great learning experience.

These comments are powerful because they demonstrate how experimentation with laptops helped students gain a deeper appreciation of technology as a potentially useful tool for learning. This is particularly helpful for students in computer science or other related vocational areas because it helps them make a connection between their school work and their future lives as professionals in the field of technology. Further, seeing laptops as "tools for experimentation and learning" may help students develop the higher-order thinking skills required in a global economy—an area where students with disabilities have traditionally faced challenges (Baker, Kameenui, & Simmons, 2002).

Exemplar 2: Laptops and Transformation of Classroom Instruction

Throughout the 3-year period of the study, we observed several instances in which the ubiquitous availability of laptop computers transformed the traditional classroom environment and altered teacher-student dynamics. In this section, we describe two examples from social studies and mathematics classes. In the first example, 12th graders were studying the Bill of Rights as part of a unit on American Government. To make the unit more meaningful and relevant to students, the teacher utilized an online resource focusing on issues making contemporary headlines that directly corresponded to the Bill of Rights and the Constitution (http://www.billofrightsinstitute.org). Through current events posted on the website, the students could see how the founding principles of the U.S. continued to affect and shape a democratic society. As the teacher pointed out, "We are not living at our founding fathers times; we are here today. Students need to know how these principles affect their own situation and lives."

In the wake of the Virginia Tech shootings, for example, the teacher and her students studied materials on gun rights on the website. Since some of the students were getting ready to attend higher education, this topic was directly relevant to them. Through easy access to the news headlines, students could discuss issues related to gun rights that directly affected them. Further, easy access to information and resources made it possible for students to pose and directly answer their own questions, therefore shifting the locus of control from the teacher to the student. Discussing the lesson the teacher noted:

> The students really enjoyed accessing information directly on their laptops. I also enjoyed it because they would ask questions and I would say, "You know, on my laptop I have exactly what you have. I know the same things you know. Let's talk about them." So the students know I am not hiding anything from them, or know something I am not telling them. They get the same information I have and I think that makes them feel more like adults and more included in what is going on in the classroom. And they like that, because I am also learning with them.

The second example comes from a mathematics classroom. In this example, students worked on a unit on financial management by researching different credit card policies online. The teacher asked students to compare and contrast two different credit cards of their choice in terms of benefits, interest rates, fees, etc. Initially, the teacher provided the students with some "buzz words" to facilitate their Internet search. As she noted, in the past students often would ask one another what they had typed in their search and what websites they had used. Although this was often acceptable, for this assignment she wanted them to explore a range of credit cards to see in what ways they are similar or different. Access to individual laptops provided students the opportunity to work independently, without depending so much on each other by asking their classmates what website they had used. Discussing her experience with this unit and other similar ones, the teacher noted that the students had initially struggled. She explained:

> I think in mathematics the students are so used to having a textbook and going from chapter one to chapter two completing math problems at the end of each chapter. This unit did not follow this structure and they felt uncomfortable. It was more work for them and they struggled but it helped them become more independent learners.

Exemplar 3: Laptops and Student Learning

In this last section, we focus on the ways in which access to laptops can bridge in-school and out-of-school experiences, empower academically challenged students, and improve learning outcomes. Discussing the value of laptops many students indicated that they helped them (a) become more organized with their study notes and as a result perform better at tests and get better course grades, (b) provided easy access to information and resources via the Internet, and (c) made their work easier and more efficient. Throughout the duration of the study, we also observed several instances in which access to laptops enabled students to pursue their own learning interests, bolstering student motivation and interest in school work. One teacher explained what she perceived to be the impact of the laptop initiative:

> I have one student whose parents used to fight to get him on the bus every morning. And this student is now up and ready every morning and does not want to miss a day of school. And his behavior is in total line with school rules because he likes to stay here.

Although other teachers and students also commented on the motivational effects of laptops and their ability to keep students organized and on task, we will focus here on the case of a student named Matt, who had identified learning disabilities and cerebral palsy, and was using a wheelchair. A student in the school's business academy, Matt collaborated with another student to plan, promote, and implement a fund-raising and awareness campaign for United Cerebral Palsy in his state. The two students put their marketing and technology skills in action by organizing a school-wide car wash, a sticker sale, and a school-wide "fund day." Their efforts not only raised about $7,000, but also earned them a third place finish at the DECA (Distributed Education Clubs of America) State conference, an international association of high school and college students studying marketing, management and entrepreneurship in business, finance, hospitality, and marketing sales and service. Discussing the project and the value of having a laptop available 24/7, Matt noted:

> I know what cerebral palsy is like. I have it. I thought it would be nice to inform people about cerebral palsy. I used the computer to conduct all of my research on cerebral palsy and prepare a multimedia presentation for the school and state competition.

Matt carried his laptop with him at the competitions, enabling him to look at his notes while presenting his project to the audience. A ripple effect of the project was the increased community outreach by the school that it generated. To help Matt, students in the automotive service technology program washed the cars, while other students helped hang posters and stickers designed and developed by Matt and his peer. The school newspaper also published an article about Matt and his peer that highlighted their achievements.

Discussion and Next Steps

Mobile computing already has gained increased popularity in schools and society as a whole. As a result, a better understanding of *how*, *under what conditions*, and *to what degree* one-to-one laptop programs work to support learning, particularly with student populations that have not received much attention to date is needed. In this chapter, we have presented examples of laptop applications that can make new learning opportunities possible for students. Although those examples may at first seem simple, they illustrate how teachers typically begin to integrate technology and how "even modest implementations of new technologies can impact how teachers teach and students learn" (Bransford, Brophy, & Williams, 2000, p. 60). In this section, we discuss these examples in light of what we know about learning and effective classroom environments.

Classroom environments that are based upon learning sciences principles such as authenticity, inquiry, collaboration, and opportunities for feedback and revisions are more likely to engage learners and help them develop a deeper and more coherent understanding of content (Blumenfeld, Kempler, & Krajcik, 2006; Songer, 2006). The applications of laptops presented in this chapter illustrated many of these principles. Specifically, the examples presented revealed types of instructional strategies that engaged students in authentic activities—those that were relevant to their own interests and future lives. For instance, students learned and practiced technology skills in authentic project contexts, studied social studies concepts through current and authentic issues, and completed mathematics and community projects that would be relevant to their lives as working adults. In the process, laptop computers made it possible for students to inquire into their own questions in collaboration with peers and their teachers and present their work in ways that were genuinely interesting to them, such as through multimedia or video presentations. In many cases, the teachers also engaged in learning that utilized the same types of information and resources available to students. In this sense, the one-to-one laptop environment facilitated community building in that it allowed for increased sharing and support even among students who were not typically looked upon for help. Increased opportunities for collaboration and sharing of multimedia products enabled students to receive feedback on their work from their peers and their teachers as well as an authentic audience, as in the case of Matt who presented his work at the DECA conference.

Most importantly, the classroom environment made possible through the use of laptops fostered an increased motivation for learning among students and served as a means of empowerment. As some teachers in the school put it, prior to joining the school many of the students involved in the laptop initiative were “not interested in learning” and were “heading for dropout.” Yet, many of them went to great lengths to complete school work and spoke with confidence and pride about school projects that they completed on their laptops. Further, students participating in an online mathematics course strongly emphasized the value of having a laptop, which enabled them to access course materials, anytime, anyplace. In fact some students completed all required coursework ahead of time and noted that for the first time they were getting high grades in mathematics. These findings are crucial given that students with disabilities often struggle to acquire a positive self-concept and a sense of competence (Rodis, Garrod, & Boscardin, 2001). Providing learning experiences with technology in which students with disabilities can experience success can help them in their future career orientations and self-image (Shaffer, 2007).

Despite the benefits described above, it is important to point out that not all laptop applications observed and documented in our work were equally meaningful to students. In many instances, we observed low-level uses of laptops such as completing worksheets, watching video clips that were poorly aligned with the stated objectives of the lesson, or simply producing word processing documents. Further, a small number of teachers continued to make minimal use of laptops in their practice, primarily due to the lack of effective professional development and a motivational system that encouraged their use.

As we look into the future, these findings point to the need for effective professional development and support that is tailored to teacher needs. Many teachers, for example, spoke about their desire for more content-focused professional development offered in small groups, as well as support in identifying digital resources closely aligned with their curricula and their students’ needs. Such professional development should also address classroom management concerns in laptop environments, such as how to keep students on task and avoid access to inappropriate materials, and address technical challenges, such as battery charging and aging technologies. Examining technology implementation practices associated with student learning gains, Means (2010) also indicated that teacher professional development should pay more attention to the details of classroom management. Teachers have different routines for organizing classroom activities and as with other aspects of teaching it will be helpful for them to observe examples of efficient classroom management strategies within the kind of setting in which they teach (Means).

In terms of further research, we clearly need more studies on the benefits of laptop programs for student learning, particularly for students with disabilities who have traditionally struggled to succeed academically (U.S. Department of Commerce, 2007). Such research should also look closely into the ways in which access to laptops for schoolwork and vocation-related tasks may open up new career opportunities for students or success in higher education following high-school graduation. Some of the students we studied, for example, questioned the relevance of their laptop experience to their future employment, although the connection was quite clear to us. Helping students with disabilities experience realistic images of professional life may be particularly valuable in guiding future choices and opening up career paths (Shaffer, 2007). Such research is essential not only in leveraging the potential of laptop programs, but also in providing guidance to an increasing number of schools who are racing to acquire the next generation of mobile computing, such as iPads and other forms of tablet computers.

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Chapter 11
Virtual Middle School Courses to Support Anytime, Anyplace Learning

Cathy Cavanaugh and Feng Liu

The middle school years constitute a unique and critical period in children's K-12 education, as it is a time when many students solidify their social, academic, and emerging professional identities. It is during this period that students make commitments to continue in school or leave. Middle school learning prepares students for the transition to high school, particularly the critical ninth grade year (Rourke, 2001) when students experience tension over increased responsibility, autonomy, and isolation (Cotton, 1996). Ninth grade is also a time when many students must earn passing grades in demanding core courses for the first time (Fulk, 2003; Smith, Akos, Lim, & Wiley, 2008). Further, academic success in ninth grade course work is more predictive of eventual graduation than demographic characteristics or prior academic achievement (Allensworth & Easton, 2007). Therefore, access to effective teachers, quality courses, and appropriately paced learning at the middle school level is pivotal for later educational success.

Flexible pacing for learning is central to meeting the needs of students across the academic spectrum. Tailoring the pace of a course to individual needs is particularly crucial for students in high-risk groups and those with disabilities (Repetto, Cavanaugh, Wayer, & Liu, 2010). Online courses are well positioned to offer flexible pacing and tailor course timelines to the needs of individual students, and thus could help close the achievement gap among students with learning disabilities and those without (Cavanaugh, 2009). The flexibility of online courses can also help ease middle school students' transition to high school. Flexible pacing of courses supports student mastery of course content, ensuring that learners have the academic foundation for high school work. In addition, the personalized interactions between teacher and student in an online course support development of learning strategies needed for success in more rigorous courses. As a result, virtual schools and public school districts have begun adding middle school courses to their offerings in order to meet the unique needs of middle school students.

C. Cavanaugh (✉) • F. Liu
College of Education, University of Florida, Gainesville, FL, USA
e-mail: cathycavanaugh@coe.ufl.edu; martinlf@ufl.edu

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This chapter examines online education at the middle school level, reporting on the growth of online middle school courses, the alignment of online learning with the cognitive needs of adolescents, and the outcomes from a large online middle school program. The chapter ends with recommendations and implications gleaned from this knowledge base for teachers, course designers, and school leaders at the middle school level.

Background

Growth in K-12 online education is likely to increase in the foreseeable future in U.S. public education as a result of Investing in Innovation (i3) funding, Race to the Top projects, and the reauthorization of the Elementary and Secondary Education Act. These initiatives along with private national programs like Next Generation Learning Challenges emphasize competency-based education and flexible pathways through school as a way to increase high school completion rates and readiness for college and career.

As of 2011, most online programs and courses in the U.S. offered at the precollege level were in grades 9–12 (Watson, Murin, Vashaw, Gemin, & Rapp, 2011). However, the demand for elementary and middle school online programs has grown as increasing numbers of students have enrolled in online education (Clark, 2007). Thus, many online high schools have started serving middle school students in advanced courses (Cavanaugh, Gillan, Bosnick, & Hess, 2008). Recent estimates indicate that 1.5 million American students, representing 5 % of the total student population, were engaged in online and blended courses during the 2009–2010 school year. Further, these numbers have increased by double-digit percentages each year between 2000 and 2010 (Wicks, 2010). The majority of these students enroll in one or more online courses in order to supplement their home school or traditional school programs (Watson et al., 2011).

Policy supporting online programs varies by state and district. Consequently, online courses are available to all students in some regions but not in others (Watson et al., 2011). Students and their families choose online courses for many reasons, including the opportunity to take a course not otherwise available at their local school, learning in a way that meets specific needs, flexibility in their school schedules, and recovering credit from courses previously failed (Picciano & Seaman, 2009). These reasons become exacerbated when schools reduce the numbers of teachers and classes during budget cuts.

Middle School Online and Blended Approaches for Differentiated Learning

Flexibility in elements, such as pacing and timing, is the hallmark of differentiated instruction (Weber & Smith, 2010). In a comprehensive, representative, and diverse national student survey, the most-cited reason among middle school students for choosing online learning was working at their own pace (Project Tomorrow, 2010). In online learning, differentiation is important in writing tasks as well as time available for course completion, both areas where online students have expressed a desire for more guidance (Thomas, 2008).

Online programs are uniquely suited to address differentiated instruction by customizing the pace of instruction and fostering increased interaction among students and teachers. Increased levels of interaction are crucial to knowledge acquisition, the development of cognitive skills, and retention of learning (Sims, 1997). At the K-12 level, research indicates that effective, consistent, and timely feedback from the course instructor can be engaging and motivating for students (Talvitie-Siple, 2007). In turn, increased motivation and engagement with school work can result in improved student understanding and more flexible use and application of knowledge in new settings (Rigby, Deci, Patrick, & Ryan, 1992; Wang & Reeves, 2007).

Online programs can also provide an effective approach to accelerating or enriching the academic opportunities of gifted K-12 students (Wallace, 2009). According to Weber and Smith (2010),

> Students who are gifted are drawn to the virtual programs because it allows them to work on their own schedules, adjust the pace as needed to suit their learning style, be flexible about adjusting the schedule and demands to suit their own preferences—options not typically available in traditional education programs. In particular, online learning fosters pre-assessment which has always been advocated for students who are gifted. Pretesting determines what the student already knows and indicates educational gaps so education can be personalized (p. 46).

There is some support for the value of online learning for gifted learners. For example, Stevens's (2008) study in which gifted middle school mathematics students were randomly assigned to classroom or online learning environments indicated that online students performed significantly higher on a content test than the classroom students. Further, their writing showed stronger general comprehension of concepts.

Similarly, findings support online education as an effective approach to differentiating instruction for students at risk for dropping out of school and for students with disabilities. As virtual schools add credit recovery and closing the achievement gap to their missions, some are now serving students with disabilities at the same rate as are served in the physical schools (Rose & Blomeyer, 2007; Watson & Gemin, 2008; WestEd, 2008). Specifically, virtual schools enroll increasing numbers of students with low-incidence disabilities, students on the autism spectrum, and learners with serious health challenges (Watson, Gemin, Ryan, & Wicks, 2009).

Online courses are beneficial to students with disabilities because they can easily integrate adaptive technology while simultaneously reducing social stigmas. Literature focusing on at-risk students, however, points out the need for differentiating instruction in ways that are compatible with virtual learning. Students need effective strategies and habits for independently controlling their learning, for maintaining momentum in the online course, and for regular interaction with teachers and other students. In controlling their learning, online students must balance increased autonomy and responsibility, while depending on verbal communication tools. The nature of the communication needed by each student is unique, and must be understood by both the students and the teacher. Online students also need engaging curriculum grounded in effective teaching strategies that supports their learning (Christle, Jolivette, & Nelson, 1999, 2007; Dunn, Chambers, & Rabren, 2004; Kortering & Braziel, 1999; National Longitudinal Transition Study 2, 2005; Scanlon & Mellard, 2002). The format of the curriculum materials must motivate students to persist in independent mastery learning by building on the affordances of the virtual and physical learning environments available to online learners.

Results from a large statewide online school enrolling students with disabilities are quite promising, indicating that students with disabilities and those from low-socioeconomic (SES) groups outperformed their counterparts in site-based schools on the state's standardized exams (Liu & Cavanaugh, 2011). These findings indicate that virtual schools are becoming a viable program option for increasing numbers of at-risk students with disabilities (see also Chap. 10 for ways in which access to laptop programs can support at-risk high school students).

Nevertheless, virtual schools operate according to a wide range of approaches and models of design and instruction. Although some virtual schools offer courses that resemble correspondence courses centered on self-paced or scheduled reading followed by writing or tests, most virtual schools provide teacher-facilitated courses featuring rich interactions and media (Watson et al., 2011). Due to the variability of online courses from school to school and the differences between online and classroom-based courses, some students perform better in online courses while others do not achieve as well as they do in classroom courses. Most studies, however, show that students perform at equivalent levels in online and classroom-based courses (Cavanaugh, 2001, 2007; Cavanaugh et al., 2008; Cavanaugh, Gillan, Kromrey, Hess, & Blomeyer, 2004).

One area where virtual schools do not fare as well as site-based schools is retention rates. Students enrolled in virtual schools often have a grace period at the start of a course during which they become oriented to the online format. Even so, the high level of motivation and responsibility required in online learning often results in early drop out rates that exceed those of site-based programs. This trend has begun to shift recently with many schools and districts using online programs to enroll students who "drop back in" to an education program after having left it (Watson et al., 2011).

Standards for Determining Quality of Virtual Courses

The design and evaluation of K-12 online courses and programs is guided by general quality standards that the International Association for K-12 Online Learning has developed. Studies show that the quality of the education provided by online courses and programs at the high school level is at least as high as in classroom-based programs (Bernard et al., 2004; Cavanaugh, 2001; Cavanaugh et al., 2004; Shachar & Neumann, 2003; Ungerleider & Burns, 2003). Performance indicators used to examine online high school programs have included Advanced Placement results, standardized examination scores, and student grade point average (Florida Tax Watch, 2007).

Few studies have reported on quality measures and student outcomes specifically for middle school programs. However, the results of a national survey that the Texas Virtual School Network conducted in 2010 to identify practices in online programs, which high school leaders perceived to be of high quality (Blackerby, 2010), can help pinpoint potential indicators. According to the survey, the most commonly reported quality indicators of online courses were (a) aligned with state content standards, (b) an articulated instructional design process, (c) course interaction, and (d) adherence to national standards for online teaching and courses. Interaction and teaching were the most highly valued and "trained facilitators and highly interactive instruction" were seen as critical to students' success (Blackerby, p. 1).

In the next section, we describe an online program for middle school students that incorporates each of the quality indicators above. We have chosen to focus on this program as an illustrative case for the following reasons: it is one of the largest public virtual schools in the U.S., it includes elementary through high school grades, it offers full-time and supplemental online programs, it enrolls students in demographic proportions representative of the state's school population, and it incorporates state curriculum standards and achievement exams in the data available for analysis. Next, we report on the factors that contributed to the students' success in the online courses. The results of this study are particularly important given the limited research available on the role of virtual schooling on early adolescents' performance and the factors that might influence their success in such environments. Moreover, they offer insights on how to design and teach online courses as middle school offerings expand into the mainstream of education.

Exemplar

Description of the Middle School Virtual Program and Courses

The case consists of a large state-run virtual school in the central U.S. that offers online courses to students in grades 6 through 8. Instructors were state-certified teachers who designed the courses to be strongly aligned to the state's content standards. Each course objective aligned to state standards for the content area and prepared students for the state's achievement exams, in accordance with the online course quality indicator related to the curriculum standards adopted.

The courses were designed according to a framework that ensured adherence to the state standards through a sequence of learning activities in course modules. This design approach is an example of the online course quality indicator recommending articulated design principles. The course activities provided many opportunities for students to interact with the teachers and media. The courses were teacher-facilitated, consisting of modules that included independent student work with digital resources and practice activities provided in the learning management system, asynchronous group discussions, synchronous tutorial sessions, synchronous help sessions, and assessments. Each module required student mastery of the learning objectives in order to advance to the following module in the course. In this way, the courses exemplified the quality indicator online school leaders value and identify as critical to school success, namely, a high level of interaction with content and the instructor.

As a quality measure, the virtual school provides professional development experiences to all online teachers in effective interaction practices, including frequent and detailed feedback to students, supportive comments to students, regular contact with students and their parents, and fostering a welcoming environment in the course. These practices are among those recommended in the national standards for quality online teaching, and they satisfy the online course quality indicator for national teaching and course standards.

Although the virtual middle school reflects qualities that are deemed key to early adolescents' successful performance in the online environment, research is needed to examine the multitude of factors that may influence students' performance. This chapter's authors conducted a study in 2008 to examine the effects of demographic variables and online course activity on course grade and state achievement test scores. Students came from public, private, and home schools and took at least one of 14 online courses in mathematics (3 courses), science (3 courses), social studies (3 courses), and language arts/English (5 courses). Data were collected from all 950 middle school students attending the virtual school during the period of 1 year, and a range of 43 to 114 students completed each course.

Demographic Factors Influencing Success in the Program's Online Courses

Demographically students were identified by gender (male/female), grade (6, 7, 8), disability status (having an Individualized Educational Plan [IEP] or not), participation level in the virtual school (full-time or part-time), and SES (enrolled in a free or reduced lunch program or not, see Sirin, 2005). It is well established that most of these variables play a role in students' learning in traditional settings. Consequently, we would expect them to be relevant in online learning as well. The participation status of students in the virtual school is of particular relevance given the variety of models that exist for online learning. Further, it is possible that the unique features of virtual courses, such as greater ability to differentiate learning, may yield results unlike those found previously, particularly for students considered at risk (e.g., girls for entering the fields of science and mathematics, students with disabilities, or children from low-SES homes). For each student enrollment in an online course, two grade level labels are possible: one for the grade level associated with the course (i.e., 7th grade science), and another for a student's grade level in his or her school program (i.e., 6th grade). Most students were enrolled in courses at their grade level; however, some students enrolled in a course above or below their grade level, depending on their readiness for remedial or advanced coursework.

Table 11.1 displays the factors that significantly influenced middle school students' academic performance in terms of final score. The "X" sign indicates that the factor had

Table 11.1 Online courses that had a significant effect on students' final score

Course/factor	Grade	Gender	Free or reduced lunch	IEP	Student status	Teacher comment	Number of times logged into LMS	Time spent in LMS
Mathematics								
Pre-algebra								
Math concepts 6th grade			–X					
Advanced math concepts 7th grade								
Science								
Comprehensive science 6th grade			–X					
Introduction to life sciences 7th grade	+X		–X					
Science survey 8th grade	–X			–X	–X			
Social studies								
Human geography 6th grade			–X					
Middle school world history 8th grade	–X							
U.S. history 7th grade			–X			–X		
Language arts/English								
Communication arts I 6th grade						–X		
Communication arts II 7th grade			–X					
Communication arts III 8th grade								
Middle school grammar and writing		–X			–X	–X		
Middle school reading			–X					
Total (out of 14)	3	1	7	1	2	3	0	0

a significant effect on students' final score in the corresponding course. The "+" and "–" signs show the direction of the effect, positive or negative. The results were obtained using a generalized estimating equation for the estimation of coefficients of the different variables. As illustrated in the table, gender did not play a major role. It had a negative and significant effect for a single course, Middle School Grammar and Writing (−5.47, $p = 0.035$), with female students outperforming the male students. This finding contradicts recent research showing that girls tend to achieve higher grades in courses (see Duckworth & Seligman, 2006, for example). Therefore, the lack of gender difference in performance on 13 of the 14 courses is encouraging. It is worth exploring in future research whether or not online technology can assist in bridging the gender gap that exists in traditional school academic performance.

The role of grade level on online learning is particularly relevant given the different reasons students enroll in virtual courses. For instance, younger students may enroll in a course that is at a level higher than their grade for enrichment purposes, while older students may enroll in the same course because they had previously failed it when offered at their traditional school. In our study, grade level did play a role though it was not pervasive. Grade level significantly influenced students' final score on two science courses (7th grade Introduction to Life Sciences [3.67, $p = 0.038$] and 8th grade Science Survey [−11.67, $p = 0.001$]) and one social studies course (8th grade Middle School World History [−8.82, $p = 0.006$]). Specifically, students enrolled in the 7th grade Introduction to Life Sciences course who were actually in a higher grade (8th grade) in their traditional schools outperformed students who were in a lower grade (6th or 7th grade). In contrast, students from lower grade levels obtained a higher score in the 8th grade Science Survey and 8th grade Middle School World History courses than students at higher grade levels. This finding can be partially explained by the fact that many students from a higher grade enrolled in the 8th grade online courses for remediation and credit recovery. Thus, the academic performance of these students was not stellar to begin with. These findings call for more research that provides a deeper understanding of grade level with respect to middle school students' online academic performance. An explanation for this effect may be that the lower grade students taking 8th grade courses were academically advanced or gifted and therefore ready for the course compared to the 8th grade students who appeared to be academically challenged.

Given that online courses and programs are viewed as being more amenable to providing differentiated instruction, examining the role of disability on middle school students' performance in an online environment is warranted. Our findings suggest that the students with disabilities did not perform significantly differently than those without disabilities except for one course. Specifically, a positive and significant effect of IEP was found on the 8th grade Science Survey course (15.77, $p = 0.000$) where students with an IEP outperformed those without an IEP. Many special education students enrolled in the virtual school were taking online courses to supplement their traditional education, and the virtual school offers or supports IEPs for these students. Although online technologies seem to have increased potential in bridging gaps between students with IEPs and those without them, this study found no significant differences in the academic performance of most special education students. It is important for all schools that principles of Universal Design for Learning (UDL) be integrated into instruction to accommodate students with different abilities (see Chap. 3, sections "Universal Design for Learning Framework" and "Exemplars" for a description and illustration of UDL principles and their relationship to teaching and learning with technology). Virtual schools may be helping students with special needs to succeed in their learning through peer support and more one-to-one instructional time any time on any day than is often available in a classroom environment.

Like gender and grade level, student school participation status played a role in students' academic performance, albeit a minor one. Status had a negative and significant effect for two courses: 6th grade Human Geography (−8.15, $p = 0.005$) and Middle School Grammar and Writing (−26.20, $p = 0.004$) with part-time online students achieving higher scores than full-time online students. Face-to-face communication between part-time students, teachers, and peers in their traditional schools could have helped them build better interpersonal relationships, which led to more peer support and cooperation and thus improved academic performance. This finding suggests that we rethink online instructional design models. It is possible that a combination of face-to-face and online instruction is more beneficial than online instruction alone.

Of all the factors, participation in free or reduced lunch programs was the most significant in influencing middle grade students' academic performance. Specifically, participation in these programs significantly influenced students' performance in 7 out of the 14 online courses: 6th grade Math Concepts (−6.02, $p = 0.003$), 6th grade Comprehensive Science (−9.64, $p = 0.000$), 6th grade Human Geography (−8.81, $p = 0.000$), 7th grade Introduction to Life Sciences (−10.55, $p = 0.000$), 7th grade U.S. History (−11.23, $p = 0.002$), Middle School Reading (−7.68, $p = 0.004$), and 7th grade Communications Arts II (−17.84, $p = 0.000$). The directions of the coefficients indicate that students not participating in free or reduced lunch programs performed better academically than those eligible for the programs. These findings are consistent with previous studies (Coleman, 1988; Klein, Hamilton, McCaffrey, & Stecher, 2000; McLoyd, 1998). Our findings suggest that virtual schools should be sensitive to the needs of low-SES students and implement measures that provide necessary resources they may be lacking that might influence their academic performance.

Classroom Activity Factors Influencing Success in the Program's Online Courses

Three factors were examined to determine the extent to which teachers and students interacted with one another and the online learning system: the number of comments teachers made to students, the number of times students accessed the online course system, and the amount of time students spent in the online course system. Although not representative of all factors needed for success in online middle school courses, they do provide a basis for partially explaining student academic performance. Typically, the most commonly accepted measure of success in online learning is the grade students earn in online courses and academic performance on standardized exams (Ronsisvalle & Watkins, 2005). However, by exploring the classroom activity factors, we are opening a window into the interactive elements of online learning, which is seen as underlying success in virtual courses (Blackerby, 2010).

Table 11.1 shows that of the three factors teacher comments had the most influence on students' final score in a course. Teacher comments had a negative and significant effect for three courses: 7th grade U.S. History (−0.21, $p = 0.045$), 6th grade Communications Arts I (−0.16, $p = 0.046$), and Middle School Grammar and Writing (−0.33, $p = 0.020$). Specifically, students who received fewer teacher comments performed better than those who received more teacher comments. This finding is quite surprising considering the positive effects of teacher comments documented in many other studies (Anderson & Kuskis, 2007; Cavanaugh et al., 2004; Dickson, 2005; Ferdig, Papanastasiou, & DiPietro, 2005; Hughes, McLeod, Brown, Maeda, & Choi, 2005; Phipps & Merisotis, 2000; Smouse, 2005; Zucker, 2005). The small sample sizes in our study could have contributed to this result. Further, we only examined the number of teacher comments and did not attend to the nature or format of the comments. More studies with a larger sample size are needed, and they should also investigate the format and content of teacher comments, as well as the ways in which they influence student outcomes (see Chap. 5, section "Impacts of MODELS and TELS on Teaching and Student Learning with Visualizations," for such information in the context of visualization).

The number of times students logged into the learning management system and the amount of time they stayed connected did not have a significant effect on scores for any of the 14 online courses. This finding contradicts popular belief that time spent on academic activities influences success in online high school education (Cavanaugh, 2007), face-to-face instruction (Rocha, 2007), and blended programs (Cavanaugh, 2009), and that the number of times students logs into the learning management system is a strong predictor of student academic performance in online learning (Dickson, 2005; Dietz, 2002). It may be the case that there is a threshold effect regarding time and performance in that most students were motivated to spend enough time in their study to perform at their best possible level and any additional time resulted in diminishing improvements. Alternately, there may be other superseding factors that mask the effects of time for middle school students, such as a student's level of literacy or maturity.

Next Steps

This exemplar case and other research that has begun to emerge on the success of middle school students in online learning shows both the potential of online education to meet the unique needs of middle school students as well as a gap in our understanding with respect to designing and teaching effective online courses at the middle school level. From the limited data available, we offer recommendations for online course designers, teachers, program leaders, and researchers.

We suggest that course designers develop online courses that offer students specific guidance and instruction, choices in assignments and projects that support differentiation, and flexible pacing through course competencies. Courses can be designed to balance online and offline learning time by building on activities done in physical learning environments with face-to-face interactions.

It is important that online instructors provide middle school students with specific feedback on their work, recognize their individual strengths and needs, and give them opportunities to interact with the content and others. Teachers can accommodate the tendency of middle school students to benefit from direct interpersonal interaction by facilitating offline activities such as clubs, reading groups, field trips, and extra-curricular activities.

Online program leaders can choose online courses that offer these features with the understanding that those courses must also be supplemented by supportive facilitation and differentiation for students. In particular, students from low-SES homes may need specific attention and supports from teachers and course facilitators, as well as embedded coaching, tutoring, and reference materials within their courses. Additionally, these students may need wrap-around services such as academic coaches, learning strategies, embedded media specialists, and counselors. The findings of this case and other recent research in K-12 learning environments indicate the power of blended educational experiences, leading us to recommend blended program designs in schools.

Researchers are needed to study in greater depth each of the factors examined in this case. Many questions remain about the effectiveness of various environments, timelines, materials, teaching strategies, and assessments for each content area and for subgroups of learners.

These guidelines do not depart in spirit from solid course design in most contexts, but the implementation of the guidelines must reflect the specific nature of early adolescent learners who are likely to be novices in most content areas, in their ability to think metacognitively, and in their social skills. Ideally, online middle school courses will scaffold students' transition to high school by developing their content knowledge, their independence as learners, their social confidence, and their interest in continued learning. We are just beginning to see what such courses look like, and now we need to examine innovative models to scale up opportunities for online education to increase student access to courses that represent best fit for each student.

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Chapter 12
The Potential of Mobile Technologies to Connect Teaching and Learning Inside and Outside of the Classroom

Mark van't Hooft

Rapid developments in mobile devices and pervasive wireless networks continuously redefine the ways in which we live, work, play, and learn. In fact, wireless mobile devices enable anytime and anywhere access to digital tools and resources in popular and easy-to-use formats and allow instant communication across time and place. As such, they place an ever-increasing amount of control in our hands and enable us to have rich user experiences as we access, aggregate, create, customize, and share digital information in a variety of formats. These unique characteristics and capabilities of wireless mobile devices provide exciting opportunities for teaching and learning that can change what is "pedagogically possible" (McClintock, 1999). Specifically, their mobility and connectivity allow students to access information at their fingertips and connect their learning to the outside world across a variety of real and digital contexts. The unique affordances of mobile technologies and their implications for teaching and learning are the focus of this chapter.

Before considering some theoretical perspectives, a few words about the evolution of mobile technologies are warranted. Mobile hardware and software have changed greatly since the 1970s and continue to do so; just compare early devices such as the Dynabook (see Chap. 3 for a description of Dynabooks), Psion, and Newton with more current devices such as iPods, tablets, portable gaming systems, and Smartphones. Due to these changes, mobile devices have been defined in many different ways (for a detailed discussion see van't Hooft & Vahey, 2007). For the purpose of this chapter, mobile devices are defined broadly as being characterized by:

- High mobility, i.e., small enough that they can be easily carried in one hand.
- A small form factor, so that they are unobtrusive and do not interfere with face-to-face interactions.

M. van't Hooft (✉)
Kent State University, Kent, OH, USA
e-mail: mark.vanthooft@gmail.com

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- Accessibility, i.e., relatively cheap, easy to use, and the ability to turn on instantly without lag time.
- Adaptability to the learning context and the learner.
- Capabilities to create, collect, access, and display a variety of information in multiple modalities (text, graphics, audio, video).
- The ability to support communication, collaboration, and sharing of information.

Devices that fit these characteristics include Personal Digital Assistants (PDAs), mobile phones, Smartphones, tablet computers such as iPads or the smaller Samsung Galaxy tab, networked graphing calculators, iPods, and other multimedia devices and handheld gaming systems. Laptop computers are excluded because they tend to be larger in size, are portable rather than mobile, and take time to be booted for use (see Chap. 10 for more information on laptop computers).

Background

Theoretical Perspectives

In the last decade or so, global popularity of mobile devices has given rise to the field of mobile learning, which is still a "distinctive yet ill-defined entity" (Traxler, 2009, p. 2). Initial attempts at identifying mobile learning were derived from the field of online learning. Scholars in this field focused on the *technology* itself, defining it as "e-learning through mobile computational devices" (Quinn, 2000, Introduction section, para. 1) or "any educational provision where the sole or dominant technologies are handheld or palmtop devices" (Traxler, 2005, p. 262).

Following this device-oriented definition of mobile learning, a more *human-centered* approach appeared, "taking a broader view that accounts for a learner freely moving in his physical (and virtual) environment" (Laouris & Eteokleous, 2005, p. 6). New definitions characterized mobile learning as "any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of learning opportunities offered by mobile technologies" (O'Malley et al., 2003, p. 6).

More recent work has taken the concept of mobility a step further by exploring the notion that mobility is not just a characteristic of individual learners but of *society* as a whole. As such, mobile learning is now being characterized by mobility in multiple areas, including physical, conceptual, and social space, technology, and time (Kukulska-Hulme, Sharples, Milrad, Arnedillo-Sánchez, & Vavoula, 2009).

Using this concept of a mobile society, Sharples, Taylor, and Vavoula (2007) proposed a theory of learning for the mobile age that takes into account learning that happens in all kinds of formal and informal environments; is based on a synthesis of research that considers effective learning as learner-centered, knowledge-centered, assessment-centered, and community-centered (Bransford, Brown, & Cocking, 2000); and takes “account of the ubiquitous use of personal and shared technology” (Sharples et al., 2007, p. 223). As such, Sharples et al. define mobile learning as “the processes of coming to know through conversations across multiple contexts amongst people and personal interactive technologies” (p. 224). Central to this definition are the ideas that *conversation*, or the sharing of understanding with the external world, drives learning and that all learning happens within a *context*.

Koole (2009) proposed a similar model. Her Framework for the Rational Analysis of Mobile Education (FRAME) “describes mobile learning as a process resulting from the convergence of mobile technologies, human learning capacities, and social interaction” (p. 25). Learners work together to actively create, share, and consume knowledge as they move from context to context and interact with other learners, information, and digital technologies. This model is valuable because it can be used to develop mobile learning devices, pedagogy, and curriculum.

In sum, definitions of mobile learning have evolved from a focus on technology to the learner to context. As Koole’s framework illustrates, however, all three are important components. Technology is important because “as mobile devices, systems and technologies become universally owned, accepted and used … the meaning and significance of learning are changing too” (Traxler, 2009, p. 7). Learners are essential because they are the ones who make meaning out of the combination of content, context, and technology. Finally, context is important because it encompasses classrooms and other learning environments, as well as the connections between them that can be amplified by the use of wireless mobile technologies. In any event, current developments in mobile learning have not provided a solid foundation for a clear theory or definition as of yet, because the field as a whole has not matured to the point of providing ample experiences and best practices from which to deduce such a theory or definition (Traxler, 2009; Winters, 2006).

Status of the Research on Mobile Learning Effectiveness

Compared to other areas, mobile learning research is still in its infancy, especially with regard to determining its impact on teaching and learning. Most existing research in this area focuses on learning in K-12 classrooms and other educational sites, such as museums and historical locations. I briefly discuss research in each of these areas here, focusing on learning as well as the impact that mobile learning in formal and informal educational contexts has on student dispositions (e.g., motivation or attitude).

Following earlier work by Naismith, Lonsdale, Vavoula, and Sharples (2005), Shin, Norris, and Soloway (2007) wrote one of the first comprehensive reviews of research on mobile learning effectiveness in K-12 education. In their review, Shin et al. found that mobile devices were used effectively for (a) researching, organizing, and expressing ideas; (b) capturing and analyzing scientific data; and (c) communicating and collaborating. They also found some initial evidence of positive impacts on student motivation and achievement. Since these reviews were published, however, much has changed. The pervasiveness of evermore capable wireless mobile devices, combined with increased professional development and district policy changes to address mobile device use, is opening new opportunities for learning and academic research.

Specifically, studies are increasingly focusing on the use of mobile technologies in individual subject areas, both inside and outside of the classroom. In science, for example, a study in a Singapore elementary school found that students using Smartphones and a “mobilized” curriculum outperformed those who did not on the end-of-year science exam (Looi et al., 2010). Similarly, a study documenting the implementation of a butterfly-watching mobile learning system for outdoor independent learning found that elementary students using the system during a fieldtrip to a butterfly farm outperformed those who used a paper guidebook on the assessment that followed (Chen, Kao, & Sheu, 2005). Finally, Ekanayake and Wishart (2011) found that the use of camera phones in science could also enhance the effectiveness of students' learning by providing opportunities for active participation and collaboration.

In mathematics, research has found that the use of mathematics software on mobile phones or PDAs can increase student development of mathematics skills as well as metacognitive thinking knowledge about mathematics strategies (Kaloo & Mohan, 2011; Lan, Sung, Tan, Lin, & Chang, 2010). Mobile phones can also be successful in building learning communities for learning mathematics outside of the classroom (Daher, 2011). Extending learning beyond school is happening in other ways as well, for example, with iPods and student-created mathematics movies (Franklin & Pei, 2008) and the development of software that connects mathematics learning to everyday activities (Alexander et al., 2010; Fabian, 2010).

Language learning is another discipline in which the use of mobile devices, such as phones and iPods, is making an impact on both content delivery and collaborative learning (Godwin-Jones, 2011; Kukulska-Hulme, 2008, 2010). Although much of the research in this area has been done at the higher education level (see Chap. 13, section “Exemplar 2: Mentira: Interactions in Communities,” for an example of an Augmented Reality game designed for undergraduate students learning Spanish), promising results related to K-12 students can be found as well. For example, one study found that using mobile devices to complement language learning in school can be effective by allowing students to take the devices home so they can practice on their own (Sandberg, Maris, & de Geus, 2011). Another study identified strategies that used mobile technologies to effectively implement collaborative reading activities for elementary students (Lan, Sung, & Chang, 2007).

In social studies, a recent study with teenagers from the U.S. and South Africa demonstrated how mobile phones could be used to increase cross-cultural awareness and communication skills (Botha, Vosloo, Kuner, & van den Berg, 2009). However, the strength of mobile learning applications in this area lies in the creation of interactive experiences on site. During such place-based learning activities, which are often presented in the form of an inquiry-based learning challenge or game, digital and physical spaces enhance each other and users are actively engaged in their own learning. Examples include (a) eXplore!, which scaffolds student learning of history during a visit to an archaeological park by means of a game (Costabile et al., 2008); (b) Premierløytnant Bielke, a mobile, location-based game for teaching and learning local history in Bergen, Norway (Wake & Baggetun, 2009); and (c) Frequency 1550, a similar game designed to learn about Amsterdam in the 1500s, which is described in greater detail in the "Exemplars" section of this chapter. Research investigating the impact of inquiry-based mobile learning on location has found that it increases elementary and secondary students' learning of social studies content, especially when tied to related classroom learning (e.g., Huizinga, Admiraal, Akkerman, & ten Dam, 2009; Shih, Chuang, & Hwang, 2010).

In addition to the above, a growing body of research suggests that the use of mobile devices improves student behavior. For example, studies indicate that classes in which mobile devices are being used have seen increased attendance, motivation, and time on task, as well as fewer behavioral problems (Finn & Vandham, 2004; Huizinga et al., 2009; Swan, van't Hooft, Kratcoski, & Unger, 2005). Further, research shows that mobile devices help reinforce students' organizational skills and encourage peer collaboration (Daher, 2011; Lan et al., 2007; Pfeifer & Robb, 2001; van't Hooft, Diaz, & Swan, 2004).

Despite the above promising findings, research on mobile learning highlights the importance of several contextual issues. Meaningful and effective integration of mobile devices by teachers requires ongoing professional development in technical, curricular, and pedagogical areas (Swan, Kratcoski, & van't Hooft, 2007). Administrative leadership is important as well, as commitment and vision at building and district levels are of fundamental importance for technology initiatives to succeed (Finn & Vandham, 2004). In addition, mobile devices offer many opportunities for ongoing assessment and reflection. To take advantage of these opportunities, teachers need to reconsider how they evaluate student learning (Penuel & Yarnall, 2005).

Exemplars

As noted above, wireless mobile technologies have been used for different learning activities, in different ways, and in different learning contexts (both real and virtual). In this section, three exemplary uses of mobile learning are presented to illustrate what is pedagogically possible when the focus is on mobility, and not necessarily on the tool or the learner.

Exemplar 1: Frequency 1550

Frequency 1550 (http://waag.org/project/frequentie) is a mobile learning game that uses Global Positioning System (GPS) and Ultra Mobile Telephone System (UMTS) technologies to let teenage students actively learn about the history of medieval Amsterdam by combining real and digital worlds. Students become part of the story by playing a group of pilgrims, competing to find a special relic as they roam the city, while using GPS-equipped Smartphones to walk historical routes and visit historical locations, access related digital information, complete location-based challenges based on the city's history, and create their own knowledge. They are supported by students at a central location who work out a team strategy, collect multimedia artifacts, check out historical references, and provide players in the field with relevant information. Students take turns at being on the street and headquarters teams so they get to play both roles. At the end of each day of playing, teams gather to reflect on the media produced, the answers given, and the strategic decisions made during the game.

Quasi-experimental research on the effectiveness of Frequency 1550 investigated how the game elicits narrative learning and influences cognitive and affective outcomes. A sample of twenty classes of high school students ($n=467$) participated in the study; ten classes used Frequency 1550 and the other ten received comparable, more traditional history instruction including lecture, group work, and individual work. Data collected consisted of researcher observations, team coach observations and interviews, digital game logs (student answers, routes followed, files created and shared), pre- and post-student surveys, post-game student debriefing, and a post-intervention history test. Results indicated that students who used Frequency 1550 participated in three types of narrative learning: receiving part of the story as spectators, partially constructing the story as directors, and participating in the story as actors. Being an actor was seen as the most interactive experience of the three as students physically experienced the story. However, the drawback was that they tended to lose sight of the bigger picture. In contrast, the headquarters team was responsible for constructing the story as directors, thereby having a better overall view than the street teams. Therefore, it was important for students to take on both the role of actor and director (Akkerman, Admiraal, & Huizinga, 2009; Huizinga et al., 2009; Waag Society, 2007).

Test results indicated that students who used Frequency 1550 learned more history content than those who received a more traditional history lesson, most likely because they learned the information within a meaningful physical context. Findings showed, however, that there was no significant difference in motivation to study history or the middle ages between students who used Frequency 1550 and those who did not (Akkerman et al., 2009; Huizinga et al., 2009; Waag Society, 2007). Although the results are mixed, they are promising as they show that mobile technologies can provide opportunities for digitally enhanced experiential learning that can lead to increased student achievement in a specific subject area.

Exemplar 2: MyArtSpace

A second example is MyArtSpace (Vavoula, Sharples, Lonsdale, Rudman, & Meek, 2007), which uses a combination of Smartphones and personal web space to provide a focused learning experience that includes setting a big question ahead of time, exploring it through a museum visit, reflecting on the visit back in the classroom or at home, and presenting the results. The technology provides the essential link across the different settings. During the museum visit, mobile phones are used to collect museum and student-created information (photos, audio recordings, text), including justifications for why certain artifacts were captured but not others. All information collected is automatically uploaded to the students' personal web space. On their phones, students can see who collected the same artifacts, providing a prompt for face-to-face interaction to enhance collaboration. Following the museum visit, students can view their personal collections online and expand on them by adding items from fellow students or the museum's online collection of digital artifacts. The collection is then organized into a personal, digital gallery that can be used for presentations or shared with a larger audience outside of school via a secure and moderated web space. MyArtSpace ran in three museums for one year and was used by approximately 3,000 students. It is currently available as the commercial service Ookl (http://www.ookl.org.uk).

An evaluation of MyArtSpace was conducted to determine its educational value. Data were collected from a group of 23 students (ages 11–14), their teachers, and participating museums based on focus groups, observations, surveys, and interviews (face-to-face, telephone, and email) before, during, and following the museum visit. Results related to learning indicate that (a) the use of mobile phones to create and upload items was appropriate and easy; (b) students were more motivated to learn and engage with the museum content; (c) students spent more time exploring the museum and said they were more likely to visit again; and (d) pre- and post-visit lessons were more enjoyable and meaningful. Further, results indicated that My ArtSpace supported students of differing abilities and topics in various subjects as well as literacy and media studies. Finally, the project showed that mobile and web-based technologies could be used effectively to connect student learning across various contexts such as school, museum, and home (Sharples, Meek, Vavoula, Lonsdale, & Rudman, 2007).

Exemplar 3: The GeoHistorian Project

The GeoHistorian Project (http://www.rcet.org/geohistorian), initiated by Kent State University's (RCET) in collaboration with the Kent Historical Society, began in Fall 2010 with funding from the National Endowment for the Humanities. Its main objective is to help K-12 students think like local historians by creating digital stories for an audience that transcends the walls of their classrooms. The project is based on work in ubiquitous computing and mobile learning that focuses on the use of mobile technologies to break down the barriers between schools and the world around us.

Participating students learn about local history, digital storytelling, and how to be a historian via a curriculum that incorporates hands-on activities, requires high-level thinking skills, and includes research at local historical sites. Final student products are digital stories about local places of historical significance that are uploaded to the Internet and are freely accessible to the general public. At each relevant physical location, a Quick Response (QR) code marker is installed. Passers-by can scan each QR code (see Fig. 12.1 for an example) with a wireless mobile device that has a built-in camera and bar code reader to access the digital story for the location they are visiting.

Fig. 12.1 Sample QR code (Marvin Kent House, Kent, OH)

The project ended in late 2011, and upon completion, approximately 100 elementary students from the city of Kent had created digital stories for 28 historical sites. In addition, the GeoHistorian curriculum was made available online. Although research associated with the project has not been completed yet, initial data analyses of pre/post tests for a sub-group of students indicated learning gains in the domains targeted by the curriculum, namely, local history, thinking like a historian, and digital storytelling. Additional research will inquire further into student learning as well as the general public's use of the QR codes and digital stories.

In summary, the examples of mobile learning described here are successful because they take advantage of the affordances that mobile and connected digital technologies provide to help break down barriers between teaching and learning inside and outside of school; barriers of space and time, between public and private spheres, and between individualized and social learning (Swan et al., 2007). Moreover, they illustrate the need for curriculum that includes the knowledge, skills, and attitudes students need to succeed in the twenty-first century, and pedagogy that is much more learner-driven and collaborative than teacher-directed and individualistic. Finally, the examples show that mobile technologies have become an integral part of a larger digital and mobile society, as indicated by the shifts in the definition of mobile learning described earlier in this chapter.

Next Steps

Mobile and wireless technologies have become an integral part of our lives outside of school, enabling us to seamlessly use digital information and tools for work, play, and learning. Pressures on educational institutions to allow for the same type of access inside of schools will continue to increase, as it seems only logical for teachers and learners to take advantage of the capabilities that increasingly powerful and versatile mobile tools such as the latest Smartphones, mobile gaming devices, and wireless tablets have to offer. However, several changes are needed for this to happen in ways that are meaningful, effective, and safe.

Teachers need to rethink boundaries, pedagogy, and curriculum. Formal education may conclude at the end of the school day, but learning does not. As the exemplars show, mobile technologies provide opportunities for teachers to bring the outside world into the classroom and the classroom into the outside world. Obviously, when boundaries change or disappear altogether, pedagogy has to accommodate for those changes. It needs to move its focus from teaching to learning, shifting responsibilities for learning (and more control) to students. Teachers also need to rethink what knowledge is important and what it means to be literate in a digital world (McClintock, 1999). We no longer live in a society that is based on industrial production, and current school curricula should reflect that. This means that (a) curriculum should include information that is digital, networked, and fluid; (b) contexts involving communication and collaboration should not be limited by the temporal and spatial boundaries of formal education; (c) assessments should reflect changes in the ways students learn; and (d) digital tools, which are increasingly mobile and connected, should be utilized for learning.

Administrators need to consider issues of acceptable use (such as privacy, safety, and intellectual property), teacher support, and a vision for learning. First and foremost, with a blurring of boundaries and increased student ownership of digital devices comes a less-clearly defined role for schools with regard to enforcing appropriate and safe use of these technologies. Although Acceptable Use Policies for technology are currently the norm in districts across the country, it is becoming less evident when and where the jurisdiction of schools ends, especially as increasing numbers of students expect to use their own digital devices on school property. Strategies that ban mobile devices and punish students for using them may no longer be effective. Instead, administrators should consider how their schools can be more pro-active and educate students on what is appropriate, ethical, and safe. Second, as with any technology implementation, teacher support is crucial. This is especially the case in situations where schools no longer determine what technologies students use. Therefore, the main focus of professional development and support should be on how to adapt curriculum and pedagogy to reflect changes in teaching and learning that the influx of wireless mobile technologies will require. Third, all of the above needs to be supported by a larger vision for learning, an activity that is increasingly learner-driven but still teacher-guided, provides for knowledge creation and sharing instead of consumption, is personalized and collaborative, is local and global, and is increasingly devoid of spatial and temporal boundaries.

Technology support also needs to redefine its role within educational settings. As schools increasingly depend on student-owned devices, educational technology departments will be tasked more with creating, maintaining, and monitoring the networks and digital spaces that support student learning than with providing hardware and software support.

Research in the next decade will be increasingly driven by attempts to measure learning in settings outside of schools and how to integrate such research with similar efforts in formal contexts. To do so, several things need to happen. First, researchers need to develop a more precise definition of mobile learning. Second, they need to create frameworks and tools for research that are rigorous, efficient, ethical, authentic, and appropriate for the technologies researched and the contexts in which they are studied. Such development is critical in order to measure learning that is increasingly fluid and unpredictable. Third, given the more active role that learners play in their own learning, it is plausible that they could become more active in research as well (i.e., as co-researchers), although doing so creates its own challenges.

Wireless mobile technologies are creating exciting opportunities for learning that transcend many boundaries. Unfortunately, while many of us benefit from using these tools in our daily lives, the same cannot be said for the majority of K-12 students in our nation's schools. Hopefully, this chapter provides some food for thought that will help fuel the discussion on how to take advantage of the affordances that mobile technologies provide for teaching and learning, no matter where or when.

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Chapter 13
Mobile Media Learning: Ubiquitous Computing Environments for the Mobile Generation

Kurt D. Squire

The 1990s opened with educators asking, "How might we equip every student with a broadband, multi-media computer?" Within 20 years, the landscape of digital media changed dramatically through mobile media (i.e., portable media players and mobile phones). Believed to be the most rapidly adopted technology in history, mobile media will soon reach 100 % market penetration with American youth (Comer & Wikle, 2008). Yet, existing pedagogical models may not fit students learning independently with their own personalized media and communication devices (Squire & Dikkers, in press). Roschelle and Pea (2002) predicted this conundrum between traditional, highly centralized learning models in which teachers might exert an Orwellian control over students' media interactions and a deeply distributed model in which students learn with near complete autonomy. Universities that ban laptops or K-12 schools that forbid the use of mobile phones best represent educators' struggle with mobile media. These practices beg the question of why did we wire (and now unwire) schools if decentralized pedagogies in which students exercise autonomy contradict the grammar of schooling?

This chapter describes research on mobile media devices both in and out of schools, arguing for an emerging model in which mobile media connect schools with their local communities. This model begins with research identifying how mobile media *personalize* learning experiences, so that students pursue learning trajectories driven by interest (see also Chap. 14, section "Personalization," for a description of this as a design principle). A student with an iPod and Wifi connection, for example, can pursue a topic of interest, such as fantasy football, by finding podcasts and joining an affinity group related to that interest. Devices can bring the outside world in through personalized online-enabled experiences, but they can also enable students to go *out* into their communities. Teachers described in this chapter

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K.D. Squire (✉)
Morgridge Institute for Research, University of Wisconsin-Madison,
Madison, WI, USA
e-mail: kurt.squire@gmail.com

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have been inspired by mobile devices to send students out into the world, making local communities the curriculum (see also Chap. 12, section "Exemplars"). Mobile devices in this model are lifelines back to teachers and the school. In both cases, mobile media learning technologies create a multiplicity of place so that students are always partially in one place, such as the classroom, and partially elsewhere.

Background

Mobile Media Learning and Augmented Reality Simulation Games

In the late 1990s, a confluence of interface advancements (such as affordable touch screens), increased cheap computational power, and improved battery life gave rise to a new communication device, the handheld computer or Personal Digital Assistant (or PDA). Within a few years, portable media players (e.g., iPods) and mobile Smartphones (e.g., Blackberry, iPhone, Android) eclipsed this market category. Mobile communication devices are believed to be the most rapid, broad adoption of communication technology in history (Comer & Wikle, 2008; Horst & Miller, 2006). As of 2008, 66 % of all youth own cell phones and almost all college students possess a mobile device (Johnson, Levine, Smith, & Stone, 2010; Rideout, Foehr, & Roberts, 2010). Most dramatically, youth use mobile devices to consume an average of 7.5 h of media daily, including an average of 3.5 h per day in which they are multi-tasking (Rideout et al.). Jenkins (2006) argues that a core affordance of digital media is in their ability to support a "participatory culture"; a culture in which students have opportunities to pursue goals of personal interest and participate in communities exploring such interests with the capacity to have real impact on social systems.

Affordances of Mobile Media

Educators' responses to mobile media technologies is generally to ban them (Clark, 2006). Arguments for banning mobile devices revolve around distraction, theft, and the potential for engaging in nefarious behaviors. Underlying these critiques is a concern that the technological affordances of mobile media, the learning practices associated with them, and ultimately their implicit pedagogies are at odds with those of school (see Buckingham & Sefton-Green, 2003). Drawing from an activity theory perspective, Waycott (2004) argues for a dialectic approach for understanding the appropriation of mobile media, suggesting that mobile media devices will transform learning cultures just as they must be designed to support their use in practice.

However, with each generation of device also comes a parade of new features, such as the integrated front facing video camera on the Apple iPhone 4GS to support video calling, creating new classes of applications few could imagine just years ago. Anticipating the development of the iPhone, Sharples (2002) designed a prototype of a mobile media device designed to be highly portable, individual, unobtrusive, available (or online) for communication, adaptable, and persistent (so as to enable the accumulation of data across time), useful, and intuitive. Similarly, Klopfer and Squire (2008) have emphasized the unique portability, social interactivity, context sensitivity, connectivity, and individuality of mobile devices, which became the core learning features of their augmented reality (AR) approach to education. Starting at MIT, this model has been taken up through collaborations with The University of Wisconsin-Madison (ARISgames.org), Harvard (HARP), Radford (SOAR), and others, each pursuing related variants (see Dunleavy, Dede, & Mitchell, 2009; Klopfer & Squire, 2008; Squire & Klopfer, 2007).

A key feature of this approach to mobile media learning is *personalization*. Sharples' (2002) vision describes how a device might track users' data and accomplishments throughout the day, serving as a conduit among learners, parents, teachers, administrators, and other communities. Indeed, current generation of mobile media applications explore how to make player data available to parents and teachers. For example, *Cosmos Chaos* on the Nintendo DS enables students to develop language skills in an entertainment game, while allowing parents and teachers to track children's learning whether the students are at school, home, or somewhere in between. These systems, however, are rarely integrated with the data systems that schools and other learning institutions use to make decisions, suggesting that we are only beginning to explore the impact of this paradigm (Collins & Halverson, 2009).

Sharples argues that these media devices enable a new paradigm of learning, which is described as *conversational*. The metaphor of conversation implies a rapid, constant back and forth across learners' goals, technological/material affordances of devices, and social context. This conversation metaphor shares affinity with situated, constructivist, and socio-cultural approaches to learning, but emphasizes how personalized media devices could become fully ingrained into learning, dramatically changing how students learn (see Sharples, Taylor, & Vavoula, 2007). This conversational approach reframes previous research on mobile learning that compares mobile media devices to desktops in terms of *where* they were used (Bannasch, 1999; Reiger & Gay, 1997), and instead investigates how such devices might disrupt traditional learning institutions. In short, research on mobile media devices is unique due to its disruptive nature. In fact, schools often ban mobile devices themselves for precisely these reasons.

Yet students own such devices in increasingly large numbers. Unlike efforts to bring wireless access to schools or to provide laptops for every child (see Chap. 10 for the use of laptop computers with high school students), youth purchase, learn to use, and master mobile media practices outside of the institutional context of schooling. As a result of their ubiquitous use outside of schools, mobile media devices become populated with personal data such as photographs, communications, and media consumed for pleasure. Classroom instruction that capitalizes on these features has the potential to drive students' learning through their interests.

Mobile Media in Social Contexts

In order to understand the disruptive potential of mobile media devices, it is useful to examine mobile media as a social *practice.* Examining mobile media use as a social practice, rather than purely as a set of technological affordances, enables researchers to understand couplings among users' goals and intentions, technological features, and social context. Studies of youth using mobile devices emphasize their empowering nature and the ways in which users employ them to transform their surroundings. For example, Ito et al. (2008) show how global urban youth use mobile media devices to transform their environments through cocooning, camping, and footprinting. Cocooning is the practice of using media devices to provide a layer of social insulation (such as through headphones); camping is the practice of using mobile devices in public spaces (such as laptop computers in coffee shops) to make public space personal; and footprinting is using mobile devices to manage records of one's activities (such as managing reward cards).

This ubiquitous connectivity and ease-of-access creates for users *multiplicity of place*; users are simultaneously in multiple places at once (Squire, 2009). For ordinary users, this might mean being in a persistent social channel (Twitter) throughout the day or being in a fantasy football league while at a physical game. Applications of mobile media for learning might leverage the context sensitivity of the devices to provide deeper experiences of place. Location-based social networking applications available on Smartphones, for example, can remediate people's experience of place by providing access to active communities of locals and allowing users to share their location with friends.

Central to this practice-based approach is that mobile media use cannot be separated from social context. Media, from this perspective, is always taken up by users in particular ways. Squire and Dikkers (2012) used a socio-cultural analysis of technology (SCOT) approach to examine how 12 youth who were given mobile media devices for 3 months used them across the day. This study concluded that mobile media functioned as *amplification* devices by strengthening participants' access to information, social networks, and power. Participants (including teachers and parents) reported few conflicts caused by mobile media, but indicated many occasions in which access to such media enabled youth to function as more capable young adults in their family, school, and work place lives. As an example, one participant who worked as a nanny frequently shared photographs of enrichment activities she planned for children in her care with their parents, allowing her to establish herself professionally and raise her rates.

Augmented Reality Games for Learning

Based on this emerging framework, a number of educators have begun exploring the potential of one particular pedagogical approach to mobile learning, called Augmented Reality (AR) Games (Klopfer & Squire, 2008; Squire &

Klopfer, 2007). This chapter discusses the AR approach more fully, using it as a context for describing the broader challenges and opportunities presented by mobile media devices. The objective is not simply to understand how to use AR games within existing activity systems, but rather to illuminate the ways in which mobile media more broadly can be used to disrupt traditional learning environments and push towards new goals that are more closely aligned with participants' goals (see DeVane & Squire, 2012).

The AR approach designs games around (a) particular locations, (b) authentic roles, (c) authentic documents, (d) narrative challenges (see Chap. 14, Case Studies of Narrative-Centered Learning Environments and Exemplar: CRYSTAL ISLAND, for an example of a virtual world designed around narration), and (e) game mechanics that sculpt user experience (see Squire & Jan, 2007). Dunleavy and Dede (in press) identifies 16 AR games for education developed by MIT, Harvard, The University of Wisconsin-Madison, FutureLab, Radford University, and The University of New Mexico, noting common roots in situated and embodied learning theory. These range from *Greenbush*, a game designed by fourth and fifth graders telling the story of their neighborhood, to *Buffalo Hunt*, a game developed by Radford University to support learning of American history that is playable anywhere. Tying these games together is a common focus on AR's capacity "to enable students to see the world around them in new ways and engage with realistic issues in a context with which the students are already connected" (Klopfer & Sheldon, 2010, p. 86).

Theoretically, this approach draws from situated learning theory and its associated pedagogical approaches. From a situated perspective, learning is deeply tied to context. Knowledge is not stored in the head, but rather stretched across tools, communities, and physical context (Greeno, 1998; Kirshner & Whitson, 1997). Like the pedagogies that situated learning theory has inspired (e.g., problem-based learning, project-based learning, place-based learning), AR games use design features such as narrative, roles, and game mechanics to create compelling, rich contexts in which learners might solve complex problems using authentic resources (Joseph, 2004). Further, the AR approach frequently includes significant opportunities for *students* and *teachers* to design experiences for one another (see Klopfer & Sheldon, 2010). The approaches presented in this chapter often couple playing pre-designed games about a location with significant design activity in which students create original games using AR design tools (see also Chap. 16, section "Exemplar 3: Transgressive Cheat Designs for Knowledge Building," for how children both play games in Whyville and create cheat sites to help win these games).

Exemplars

This section presents three exemplars of AR games designed to operate within normal school constraints: *Saving Lake Wingra*, *Mentira*, and *Mobile Design Workshop*. Each game is relatively focused and tied to specific learning objectives, although many interesting learning opportunities exist at the intersections of domains (such as reading comprehension of non-fiction texts, Spanish language and culture, or science and technology fluency).

Although each game was developed independently, they all spring from a common shared history (see Klopfer & Squire, 2008), exist in conversation with one another, and investigate complementary themes. In some cases, they also share underlying technology; *Saving Lake Wingra* was developed using the MIT Augmented Reality Engine (MITAR). *Mentira* was developed using the Augmented Reality and Interactive Storytelling system (ARIS), and the *Design Workshop* has used both, but ultimately gravitated toward free open source tools.

Exemplar 1: Saving Lake Wingra: The World as a Gameboard Through Layers of Data

> Welcome to EcoDesigns. We are excited to have you on board! The City of Madison has hired us to investigate Lake Wingra and its surroundings. Some people say that Madison's lakes are the most valuable part of our city. Citizen groups want the City Council to make changes to the Lake Wingra area. Some want to restore the lake to what it was like 100 years ago. They have plans to reduce *stormwater* runoff and reduce *invasive species*. Others want to strengthen the local economy with housing and businesses near the lakeshore. They have plans to build a *condo* and another *marina*. Your job is to learn more about these plans and decide which is best. You will argue for or against one of the plans before the *City Council* in 2 weeks. Expect a big crowd!

With the preceding employee orientation, several classrooms in the Madison, WI area were transformed from teachers and students to teams of project managers and landscape architects, environmental historians, and watershed ecologists as part of their participation in *Saving Lake Wingra*, a place-based AR curriculum unit designed around Lake Wingra in Madison. Taught by teams of Language Arts and Science teachers, the goals were to: (a) embed students in real-world contexts in which they *read for information and comprehend specialized language*; (b) teach students *to analyze statistical data* encountered in complex situations to develop convincing arguments; (c) engage students in using evidence to *speak and write persuasively*; and (d) facilitate the production of *higher-order thinking skills*. Each of these learning goals was co-developed by teachers who taught earlier iterations of the Lake Wingra curriculum.

In the model 2-week curriculum, which teachers adapted as they pleased, students researched and visited Lake Wingra and made presentations before a mock city council. After the initial employee orientation, students watched a fictional news report about Lake Wingra, applied for jobs at EcoDesigns, researched plans for Lake Wingra, and were briefed on persuasive speaking and writing techniques that citizens might use. For example, students were introduced to *name-dropping* as a pervasive technique and asked to note when characters name-dropped famous local personalities. Pete Vang, for instance, a Hmong angler who fished for a type of invasive species called carp, described how various ethnic groups used the lake for different purposes. Vang used emotional appeals to explain how removing carp from Lake Wingra would take away something important to him.

Roles and characters in *Saving Lake Wingra* were designed to support the formation of projective identities, hybrid identities between players and their roles. However, students often identified most strongly with ideas and values presented through fictional characters. One of the more memorable learning moments occurred when a Hmong student encountered Pete Vang and spontaneously shouted, "He's like me! He's Hmong!" Facilitating *memorable moments* is core to the theory of aesthetics and games. Drawing from Seldes (1924), Jenkins (2006) describes memorable moments as a key element of the emotional landscape of popular culture. Many design techniques can create memorable moments, including breaking the third barrier, or the well-timed introduction of novelty so as to reframe players' expectations (Squire & Jenkins, 2003). Educators might set up memorable learning moments in which students' existing understandings (or models, scripts, identities) are challenged to create emotional impact (Squire, 2011). In *Saving Lake Wingra*, designers created characters to directly reflect players' experiences and values, consistent with culturally relevant pedagogy (see Ladson-Billings, 1994).

The field-based interactions that accompanied the game involved players observing phenomena in the world. For example, at the storm sewer outlet, players were asked to look for the outlet, determine where the storm water comes from, note debris surrounding the outlet, and watch a video of Professor Jim Lorman (an actual ecologist) talking about storm water that was filmed on location. Similarly, as players walked out onto the boardwalk, they were asked to look and listen for Red-winged blackbirds, which are an important indicator species for wetlands' health. Interactions such as these were designed to require players to put down their handhelds and make observations in the field, but AR designers continuously struggled with how to best "pull students' noses" up from their devices. Students also read about the origins of boardwalk, which was built through collaboration among students at the Edgewood College, high school, and elementary school. They were also able to walk into the lake without damaging the wetlands. These features were included to illustrate how ordinary people could take ownership over the lake, and propel the student toward doing the same.

The curriculum was designed to support further reading and research. Back in the classroom, students researched relevant stakeholder groups to gain multiple perspectives that would assist in examining plans for the lake. These groups included fictitious groups, such as an eco-friendly condo association that promotes new urbanist practices, and authentic groups such as the Yahara fishing club, Friends of Lake Wingra, and the Dudgeon Monroe Neighborhood. A variety of scaffolds helped students examine plans, provide evidence for and against each plan, and identify persuasive argument techniques. Students studied charts of Chloride levels in Madison lakes, maps depicting Lake Wingra pre-settlement (1837), historical descriptions of Lake Wingra going back to 1927, and a variety of documents pertaining to Lake Wingra. All information was linked to roles so that participants delved into a topic and then reported back to their group, a design intended to support reflection. A limitation of this approach is that attaching cognitive strategies to narrative roles (e.g., the landscape architect), rather than cognitive strategies roles (e.g., the question asker), may limit their transference. As a result, we encourage teachers to continue using the reading strategies that they already employ in class (e.g., taking on roles of explaining or predicting) in conjunction with the Saving Lake Wingra AR Game, or to apply these strategies elsewhere in their curriculum.

Much like earlier iterations of AR Games (see Klopfer & Squire, 2008; Squire & Jan, 2007), playing *Saving Lake Wingra* frequently produced arguments among group members. In the following exchange, the group puzzles through the concept of invasive species, which came up because group members interpreted the texts differently.

Caine: They (Jack and Tina) two have different definition of invasive species.
MJ: What's your definition (of invasive species)?
Jack: It's sort of like what happened in the 16th century when people from Europe came over here. That sort of … considered invasive species.
Tina: Like if you took fish from a different lake and put it into Lake Wingra, it will be invasive.
Caine: Like if you put a (inaudible) and put it into Lake Wingra, they will call it invasive species.
Tina: Yeah.
Jack: Even if it is the same species, it's still invasive.
Caine: I disagree with that.
Jack: It's still invasive because it's invading…
MJ: Do you (Caine) want to give us the reason why you disagree with that statement?
Caine: Well, because if it's the same species, it wouldn't really matter. If you brought, say, a muskellunge from Lake Mendota and put it into Lake Wingra, I mean it's the same species…
Tina: But they are from different places.
Caine: Yeah (interrupted by Tina).
Tina: They are invasive!
Caine: I disagree (showing disapproval with his hands).

Jan (2010) shows that these arguments generally reflected a quality level higher than one might predict (see Kuhn, 2005). Perhaps, players readily marshaled evidence from personal experience and other resources outside the curriculum because of their emotional investment. Jan also warns that most students gravitated toward arguments that aligned with their personal experience and pre-existing views. For educators using games, it may be essential to design memorable moments that explicitly address and challenge existing views (e.g., naïve conceptions of developers vs. conservationists).

The project culminated in presentations to the mock city council and written reflections on the experience. In fact, in the years since *Saving Lake Wingra* was developed, some of the proposed ideas, like a second marina, have been implemented. Teachers remarked that students' comments were higher in quality than what they normally saw from those students. The following quotation from Jan (2010) is from a student who synthesized ideas in relatively novel ways (p. 248).

> I think that we should combine all four plans to clean up Lake Wingra. We should use the revenue from the condo plan and the Marina plan to finance the stormwater and invasive

> species. Not only would this clean up the lake but potentially create new jobs. The City of Madison could hire people with little or no education, pay them minimum wage or slightly above to take out invasive species. We could also sell condos for top dollar so maybe we could build a water treatment plant. If we do this, it will clean up the lake, create new jobs and homes, and make the lake more enjoyable. More people would use the lake and it would be clean. As for the condos and the marina, we would use only green materials and we would have to put signs that say No Littering and have monthly cleanups of the beaches. I would also like to limit the lake to non-motor boats until the lake is cleaner. For the storm-water plant, if we build the water treatment plant, we can clean up the water and then put it into the lake. We'd also have to build rain gardens all along the shores. For the invasive species plan, as I said before, we can hire people to take out the invasive species. This plan will make everybody happy.

Whereas some students synthesized arguments across experiences and data sets, as illustrated above, others created formulaic responses largely comprised of copying text into their responses, such as this passage: *People who love being close to nature will pay top dollars for these condos bringing tax dollars that can be spent on improving the lake!!!* Even in this case, the teacher remarked that the student was more engaged than usual, and copying and pasting text was a step forward from her normal performance. This occurrence serves as a caution nonetheless.

Exemplar 2: Mentira: Interactions in Communities

Mentira, which launched in July 2009 (see Li, 2010), is an AR game designed for college students at the University of New Mexico. Chris Holden, who had worked on *Saving Lake Wingra*, partnered with Julie Sykes, a Spanish Language teacher, to create a game that sent students into Spanish speaking neighborhoods of Albuquerque to use language in context. Holden and Sykes (2011) saw that mobile technologies might be used to introduce students to Mexican-American culture and encourage them to identify as fluent Spanish speakers. In short, *Mentira* addresses the recognized need of developing intercultural competence, rather than learning *about* a language (see Sykes, 2009).

Mentira is set in Los Griegos neighborhood in Albuquerque/Los Ranchos. Although *Mentira* uses AR technologies to send students into the community and introduce specific language interactions (such as how to purchase items at a store), its deeper purpose is to engage students in local Spanish speaking communities. As Holden and Sykes (n.d., para. 1) describe:

> The backbone of this project is a focus on a natural context, outside the classroom, for the study of Spanish, and the development of materials for use in that context. We chose the Los Griegos neighborhood in Albuquerque/Los Ranchos for its connection to the Spanish language, documented history, diverse use and architecture, and walkability. We used information collected from neighborhood contacts, documentary archives, and a thesis written about the area, as well as multiple site visits from which to build the story and setting.

This description captures the interplay among theoretical and practical concerns that go into designing an AR game. *Mentira* consists of approximately 70 pages of dialogue and expository text (mostly in Spanish), 150 pieces of visual art, and 4 short films. Creating and gathering such an archive is a research project in and of itself, and choosing a community with a documented history enabled the design team to quickly focus on sculpting the game experience.

Mentira employs a fictional murder mystery narrative designed to engage young adults in mystery and intrigue. The basic game structure involves conversations between the player and historically plausible characters. After some deliberation, the *Mentira* design team decided *not* to include conversations with actual Los Greigos inhabitants, despite the pedagogical potential of this activity, in order to remain respectful to the neighborhoods and not inundate neighborhood residents with scores of students. Since the game required players to enter and investigate the neighborhood, however, there were ample side opportunities for players to choose to practice Spanish, observe Mexican-American culture in the neighborhood, and most critically, experience border crossing as they enter the Los Greigos.

As of this writing, *Mentira* is in its third semester of use at the University of New Mexico, and is expected to be a typical part of the Spanish curriculum. To play *Mentira*, students are loaned an iPod Touch for 2–3 weeks. This format enables students to play *Mentira* at their leisure and integrate game play into their lives. Periodic class activities draw from and reinforce game activities, tying it to the broader curriculum. In the next phase, students travel to Los Griegos in groups and look for clues to the murder on site. Although ARIS can detect players' location through WiFi positioning, the lack of consistent WiFi access in Los Griegos required *Mentira*'*s* developers to design puzzles that required being in the *physical* location, such as noting a street sign or looking at a building from a particular angle to identify a unique feature.

As *Mentira* moves from a pilot project to an integrated part of the curriculum, researchers are investigating how players experience the game, what they find valuable, and what impact this experience has on learning. One encouraging sign was that students played *Mentira* in their spare time as evidenced by data collected on the ARIS website. In the spring implementation, students conducted an average number of 3.4 game sessions, spending on average 43 min on the homework portion. Further, 24/30 participants (80 %) completed the homework portion of the game.

Tracking players' data led to other insights. For example, although Mira (a pseudonym) was given access to the game on week 3, she did not log in to watch the video until three classes later. For most of the semester, Mira played rarely, if ever. Finally, near the end of the term, she and another student (who also had not played) somewhat inexplicably logged in and completed all three levels, each playing for well over an hour outside of class. This example (explored further in Holden & Sykes, 2011) is but a beginning in tracking how players access resources outside of class *as a normal part of instruction*. It also suggests how learning might change once we assume that students have access to learning materials 24/7, and crucially, once we seek to build learning experiences that dovetail naturally with students' everyday life patterns. These two students playing *Mentira* occurred somewhat serendipitously; imagine games in which teachers (or other students) designed interactions for interstitial moments such as walking to school, grocery shopping, or attending a public event (such as a city council meeting). For *Mentira*'*s* designers, creating these connections between the university and the community was the most valuable component of the experience, irrespective of student learning.

Both *Saving Lake Wingra* and *Mentira* attempt to realize a century old ideal of breaking down the walls of the classroom so that participation in the curriculum is not preparation for life but rather participation in life (cf. Dewey, 1927). Pursuing this goal means designing experiences that introduce learners to authentic issues with ties to curricular concerns, such as problem solving with scientific knowledge and tools and participating in different cultural discourses. Tools like ARIS are a way for educators to build youth interest for participating in sophisticated activities, pushing them toward more authentic participation so that they might decide to volunteer at Lake Wingra or participate in community functions in a neighborhood, such as Los Greigos (see Chap. 9, section "Exemplar 2: Civic Engagement with a Social Networking Application," for how a social network site can be utilized to foster student participation in civic and political activities).

Exemplar 3: Mobile Design Workshop

Unlike the previous two exemplars, which described researcher-directed experiments on the use of mobile learning, *Mobile Design Workshop*, designed by Mathews and Wagler (2009), illustrates how teachers can seamlessly integrate a variety of devices into classroom practice. Mobile Design Workshop is a semester-long high school course in which students: (a) played mobile games based on their location; (b) designed mobile gaming experiences in a series of "design jam" contexts; and (c) created a joint, collaborative AR game about their community. The class began with a visit to their City Manager's office, where the manager briefed students on issues facing their city. Rather than create a fictional character to situate the problem, Mathews and Wagler led the class to the actual city manager and discussed actual problems confronting their community. They then photographed their city, interviewed residents, and collected data on issues ranging from parking to graffiti. Although they provided access to Smartphones, students most often used digital cameras, iPods, digital recorders, and other tools—many of which they owned themselves—suggesting a potential for scalability.

After investigating their community, the class chose to design a game about the Nature Conservancy behind their school, which required them to engage in complex media production practices. In the process of designing the game, students (a) read a variety of primary documents, maps, and planning documents; (b) conducted interviews and wrote notes; (c) created fictional characters and wrote game dialogue; and (d) wrestled with common issues such as design specifications, naming conventions, and work flow patterns. Mathews and Wagler (2009) taught these skills explicitly for several weeks.

A challenge and opportunity for such pedagogies is the interdisciplinary nature of learning through design. In researching the game, students confronted others' perspectives on the conservancy, which matches a core social studies standard in most states. In post interviews, students reported learning to adopt perspectives beyond their own, particularly coming to an understanding about accessibility issues for residents (e.g., a paved path opened access to the conservancy to a much broader range of people). This is a noteworthy finding because developing empathy for other perspectives on local issues is rarely taught in the U.S., despite its inclusion as a core standard in social studies.

In addition to enhancing teachers' abilities to address standards that may be otherwise difficult to do, the interdisciplinary nature of game design is aptly suited to target core standards from multiple domains. For instance, students in the Mobile Design Workshop analyzed primary documents, studied local history, and weighed choices about the future of their community (Social Studies standards). They read expository texts for meaning and wrote across a variety of genres (Language Arts standards). One can imagine future classes seeking to organize learning experiences by design tasks rather than by subject while ensuring that content standards are covered within these activities, something that problem-based learning educators frequently did throughout the 1990s (Savery & Duffy, 1995).

More broadly speaking, this curriculum contains at least two key features that may be required of any curriculum when designing for a mobile generation. First, it involves using a pedagogy that *leverages technology that students own*. For the duration of the course, Mathews and Wagler enabled students to use any mobile device to check emails, text message, or even place or take phone calls as necessary. There were occasional discussions about etiquette, but during the semester there were no reported disruptions at all. Rather than working in competition with class activities, mobile media devices supported them.

Second, it creates an *open classroom that invites engagement from students 24/7*. On some days, Mathews and Wagler planned field trips (such as the trip to the City Manager's office). On other days, students were free to enter or leave the class as they wished to plan their own. Students interviewed local business owners, photographed their neighborhood, and generally came and went as was necessary to complete their work. As Mathews and Wagler noted, this open door policy was somewhat controversial, but it was also somewhat puzzling given that the same students functioned as young adults *outside* the normal school day. Many students were able to integrate activities into their work lives as well.

Next Steps

This chapter began by articulating a growing contradiction between mobile media learning in the everyday lives of youth and the construction of school. The pedagogical affordances of mobile devices, particularly their personalized nature, capacity to remediate space, and potential for supporting participatory learning, create opportunities and challenges. Whether or not one decides to embrace AR Games, Mathews and Wagler's design studio challenges some of our basic assumptions about education, particularly the relationship between school and the outside world. We will shortly inhabit a world in which every student will have a broadband enabled, 3D computer in his or her pocket. When every student has such a device, information from the outside can, and probably should, come inside the classroom. Likewise, there is a metaphorical and very real sense that these technologies take youth *out* of the classroom and into the world. Indeed, if educators dreamed that the Internet might break down the walls of the classroom, mobile media devices remind us that great energy has been invested in putting *up* walls around the classroom, keeping youth from participating in every day society. Devices, such as mobile phones, make maintaining contact with youth whom might be spread across a city doing investigations easier than ever, but this very idea reminds us that perhaps cordoning youth off from society has been a tacit purpose of school all along.

Next iterations of mobile media interventions (like Mobile Design Workshop) build upon students' interests and use local problems to create opportunities to become active participants in the world. Yet, today's educational system is moving further away from supporting students pursuing questions, ideas, and issues of personal and professional relevance, opting instead to measure them lockstep along a set of predetermined learning objectives determined by panels of experts. Programs such as those described here will probably continue, and middle-class and upper middle-class parents may ensure that their youth have opportunities to participate in such programs, develop their interests, and gain valuable experiences participating in adult worlds. The real question for educators will be who has access to such experiences, and whether in the name of equity, we design out of the formal education those very experiences that struggling students need the most. Thus, the primary challenges confronting researchers working with mobile media over the next decade center around creating the right ecology to support student-driven pedagogy. If we assume that mobile platforms will proliferate, how can we create digital tools that are easy for teachers and students to use and simultaneously help them confront increasing pressures for accountability? Tools like ARIS need to be made not just simpler and intuitive, but they must also help teachers, parents, students, and administrators meet their goals. How can we educate parents, teachers, and the public about the challenges and opportunities facing students, teachers, schools, and learners as well as the potential of mobile technologies and associated pedagogies to address these challenges?

The exemplars described in this chapter illustrate that the opportunities and challenges presented by mobile media are primarily social and not technical ones. The current challenge, for example, does not lie in how to equip students with the technological tools they need to participate in a knowledge economy. Schools we partner with are often more concerned with how to keep the Internet *out* of classrooms rather than bringing it in. Given the proliferation of Internet-enabled mobile devices, one piece of advice we give schools interested in adapting toward participatory and digital culture is to provide open ubiquitous wireless access so that students with mobile devices can connect. Simply becoming an "open" school in which such connectivity is not just permitted but encouraged could create change.

Of course, this generation of pedagogical improvements faces the same key challenge that has faced educators the last 30 years: How can we create assessment systems that document the compelling, complex learning occurring through such media practices? Can we provide teachers, students, administrators, and other stakeholders with data on students' learning to provide a full picture of learning and a better basis for making choices across tools and programs? This challenge has defined much of design-based research over the past 30 years (particularly the challenge of measuring learning once interventions go beyond researcher participation). Ultimately, alliances among researchers, publishers, and assessment agencies may emerge to revolutionize how data are used for learning. For now, however, the ecology has stabilized around relatively entrenched forces and appears to require substantial perturbations to destabilize.

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Part IV
Technologies that Support Learning by Gaming

Chapter 14
Design Principles for Creating Educational Virtual Worlds

Brian C. Nelson, Diane Jass Ketelhut, Younsu Kim, Cecile Foshee, and Kent Slack

Virtual worlds have existed in one form or another since the 1950s, but have recently grown in prominence as platforms for hosting educational curricula centered on learning activities which are situated in simulations of the visual contexts and functional processes in the real world (Clark, Nelson, Sengupta, & D'Angelo, 2009). Their growth has been partially in response to a growing lack of engagement, and thus lack of learning, of students enrolled in traditional K-12 classrooms. Virtual worlds offer a platform similar to gaming environments that are ubiquitous in students' non-school lives, and it is thought that capitalizing on this popular pastime might offer a way to re-engage students in learning (Nelson & Ketelhut, 2007). In virtual worlds, students control avatars that act as their representatives inside an immersive game space. Learners can guide their avatars through visually and aurally complex worlds, interacting with the objects they encounter in authentic ways. For example, students can view books in digital libraries, talk to computer-based residents of virtual towns, and test the water quality of rivers and lakes to solve narrative-based problems (see Chap. 16, section "Exemplars," for descriptions of activities observed in a virtual world for tweens focused on narratives).

B.C. Nelson (✉) • Y. Kim
School of Computing, Informatics,
and Decision Systems Engineering, Arizona State University,
Tempe, AZ, USA
e-mail: brian.nelson@asu.edu; yskim1@asu.edu

D.J. Ketelhut
College of Education, University of Maryland,
College Park, MD, USA
e-mail: djk@umd.edu

C. Foshee • K. Slack
Mary Lou Fulton Teachers College, Arizona State University,
Tempe, AZ, USA
e-mail: cecile.foshee@asu.edu; kjslack@asu.edu

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A number of researchers have demonstrated the positive impact of virtual worlds on student learning and motivation, especially in regard to middle and high school science education (e.g., Barab, Arici, & Jackson, 2005; Kafai, Quintero, & Feldon, 2010; Nelson, 2007; Slator, Hill, & Del Val, 2004). Many of the early educational virtual world projects have centered on the creation of science curricula, implemented with middle and high school students, and applied situated learning and socio-constructivist theories to the curriculum design (for a review, see Nelson & Ketelhut, 2007). Additionally, researchers are investigating ways in which they can design virtual worlds to best support the curricula embedded in them (Nelson & Erlandson, 2008). For example, one issue with virtual worlds for learning is the difficulty students have in finding a balance between learning in and playing with the worlds. A goal of using virtual worlds is to harness play for learning, but virtual worlds present a much higher complexity level than students are used to with typical textbook-based curricula. As a result, students sometimes get lost in the worlds, losing out on the learning opportunities presented. One approach to solving this problem is to use so-called *multimedia principles* based on cognitive processing theory in the design of virtual worlds. Researchers and virtual world designers are exploring the extent to which multimedia principles may reduce the complexity or "high cognitive load" experienced by students in virtual worlds, and thus bolster student engagement in virtual world-based curricula and improve learning outcomes (Erlandson, Nelson, & Savenye, 2010; van der Spek, van Oostendorp, Wouters, & Aarnoudse, 2010).

In this chapter, we discuss the use of multimedia design principles in creating educational virtual worlds. We first offer a background overview of cognitive processing-based design principles and related studies. Then we highlight two early exemplar projects that are exploring the use of multimedia design principles in the design of virtual worlds, summarize results from studies using these worlds, describe next steps for designing virtual worlds using these principles, and discuss implications for implementing virtual worlds in K-12 classrooms.

Background

According to cognitive processing theory, people can only process a small amount of information at any given moment in working memory. If they must deal with too much incoming information, or if the information is presented in a confusing or overly complex way, they will experience "cognitive overload" and their learning will be negatively impacted (Sweller, 1988). To avoid this outcome, researchers try to discover ways to design instructional materials that help learners make the most of their limited working memory capacity (Reiser & Dempsey, 2007). In doing so, they hope to help learners more efficiently move information from short-term to long-term memory, therefore improving learning. In the field of computer-based instruction, cognitive processing-based design principles are applied through what is called "multimedia learning." Mayer and Moreno (2003) describe multimedia learning as learning from words and pictures, and multimedia environments are designed in a way that fosters learning by supporting the formation of mental representations of incoming information. Mayer, Moreno, and others have described a collection of design principles based on cognitive processing theory for the creation of learning materials. These principles offer guidelines for how text, pictures, sounds, animations, etc. can be arranged to best support learning. The guidelines focus on lowering a learner's perceived extraneous cognitive load (the amount of mental effort the learner uses to deal with information that is not related to the learning goals), while supporting germane load (mental effort expended on processing information that is central to the learning goals). There are a large number of these design principles, but the ones most relevant to our discussion in this chapter include modality, signaling, contiguity, and personalization. Research has shown that application of these principles in the design of learning environments can often be effective in reducing learners' perceived cognitive load, supporting improved learning, and bolstering student engagement.

Let's look briefly at the research around these design principles as a foundation for our discussion of their use in creating educational virtual worlds.

Modality

The modality principle states that cognitive load can be reduced and learning improved when words presented with graphics in a learning environment are spoken rather than printed. This is based on an assumption that use of spoken words in conjunction with visuals allows more information to be processed in working memory by reducing a "split attention" effect in which a learner must switch focus between multiple areas of information on a screen (Chandler & Sweller, 1992). Erlandson et al. (2010) implemented the modality principle in a virtual world in which students worked in small teams to complete a disease investigation. In the Simlandia virtual world, student teams were randomly assigned to use either text-based or voice-based tools to communicate with their teammates as they conducted their investigation. The study compared student cognitive load, engagement, and learning outcomes between students communicating by voice and those communicating through the text-based chat tool. The cognitive load measure was a self-report instrument employing a 10-point rating scale shown to be sensitive to small changes in perceived cognitive load (Paas & van Merriënboer, 1994). Learning was assessed using a pre- and post-implementation content test consisting of 29 items dealing with science inquiry procedures and disease transmission. A single post-implementation "yes-no" question was asked to evaluate engagement: "Did you feel like a scientist when you used Simlandia?"

Findings from the study showed that students using a voice modality chat tool reported significantly lower overall cognitive load in dealing with the virtual world ($p < 0.05$) and lower levels of cognitive load specifically related to team communication ($p < 0.01$) than students using the text-based chat tool. In addition, students communicating via voice were more likely to report that they "felt like a scientist" ($p < 0.05$) while completing the curriculum than those conveying ideas through text. At the same time, however, there was no significant difference in learning outcomes between the two groups. Both the voice and text modality groups answered most of the questions correctly on both pre- and post-tests. Erlandson et al. speculated that the test was too easy for the undergraduate population, with most students knowing the answers before completing the virtual world curriculum.

Signaling

The second principle, signaling, involves the use of visual or auditory cues that direct learner attention to instructional material important to learning goals, while simultaneously shifting learner attention away from less germane material. By directing attention through signaling, it is thought that learning can be improved because it allows the learner to focus more "processing power" on content relevant material. Mautone and Mayer (2001) demonstrated both the usefulness and limitations of the signaling principle for the design of multimedia instructional material in a study with 86 undergraduate students. In the study, participants took part in a lesson about how airplanes achieve lift, and were randomly assigned to one of four treatment groups. The lesson included a series of animations presented on screen, along with a narration explaining the process of lift. In the "full signal" treatment, animations were signaled using arrows to point to relevant part of the images in the animations and to help depict concepts, such as airflow over the airplane wing. In this treatment, the narration was also signaled by having a narrator speak "headings" that briefly summarized the main points before each section of content, as well as narrate a brief summary paragraph before the main content portion of the lesson. Other students had either a non-signaled version of the lesson, or versions in which either the narration or animations were signaled. Mautone and Mayer (2001) found no significant effects of signaling on students' learning of the material in the lesson, but students who received the combined narration and animation signaling version of the lesson performed significantly better on a transfer test than learners in the other three conditions ($p < 0.01$). Ozcelik, Arslan-Ari, and Cagiltay (2010) conducted a study with similar results (students using a signaled multimedia learning environment outperformed non-signaled students on a transfer test, but not on a basic knowledge test). In addition, Ozcelik et al. used eye-tracking data to demonstrate that students viewing the signaled version of the software spent more time looking at content relevant images and less time conducting visual searches of the screen than students in the non-signaled version. This finding demonstrated that signaling was working as intended, namely, to guide learners' attention to material relevant to the learning goals.

Looking specifically at the use of signaling in educational virtual worlds, van der Spek et al. (2010) added auditory cues to a training game called Code Red Triage, which teaches players how to perform triage (categorizing victims at an accident scene). The audio signals were designed to help guide players to the relevant pieces of information in the game, without reducing the player's sense of immersion in the virtual world. However, in a study with 21 undergraduate students, van der Spek et al. found that the participants who received audio signaling as they worked through the triage procedure in the virtual world performed no better than participants in the non-signaled version on pre/post-tests about triage procedures. The authors suggest that the players may not have noticed the auditory signals, and propose that more overt visual signaling may be more effective.

Contiguity

The contiguity principle states that cognitive load can be reduced and learning better supported when related materials (e.g., a picture and a related caption explaining the picture) are presented near each other rather than farther apart. If words and related pictures are located far from each other, learners need to engage in a scanning process while holding specific elements of information from two more locations in their memory simultaneously. However, presenting words and related images close together can help learners by reducing the mental effort involved in scanning and integrating both sources of material.

Past studies on the use of the contiguity principle with computer-based instructional materials have shown promising results. For example, Moreno and Mayer (1999) compared learning outcomes from a computer-based instructional module about the processes that form lightning between students who viewed on-screen text placed far from related animations and students who viewed text placed close to relevant animations. Students who viewed the version of the software in which text and related images were close together performed better on both recall and transfer tests of the lightening process than learners who viewed the information presented farther apart. The contiguity principle has been shown to have a positive impact on students' perceived extraneous cognitive load as well. Cierniak, Scheiter, and Gerjets (2009) compared learning and perceived cognitive load between students viewing an integrated words and pictures format of a computer-based lesson about kidney function and students viewing a lesson in which words and pictures were not visually integrated. Students viewing the version of the lesson incorporating the contiguity principle reported less difficulty in learning the content and in learning with the material, while at the same time indicating higher concentration levels as they completed the lesson than learners for whom the content was not integrated.

Personalization

Another multimedia principle that we feel is applicable to virtual worlds is the personalization principle. Mayer (2005) defines personalization as the ability for "people to learn more deeply when words in a multimedia presentation are in conversational style rather than formal style" (p. 201). Mayer, Fennell, Farmer, and Campbell (2004) investigated the effects of personalization in the design of a computer-based learning environment on the human respiratory system. Personalization was achieved by simply replacing the word "the" for the word "you" in the narration of the respiratory system animations. They found that learners in the personalized condition engaged in deeper cognitive processing as evidenced by the group's significantly higher transfer tests scores ($p = 0.02$) over students in the non-personalized condition.

The personalization principle can be applied more broadly than Mayer's definition above. For example, personalization can be achieved by allowing learners to create a customized space representing their interests and choices. Maxwell and Chmielewski (2008) found that allowing students to personalize their learning environment could bolster first-graders' self-esteem and may in turn influence motivation. Personalization in the study was carried out by not only posting each child's birthday, photos, and art projects in the classroom, but also by allowing the children to create the bulletin boards and frames for their own artwork. The students in the personalized classroom showed a significant positive effect on self-esteem ($p < 0.03$) over those in the non-personalized classroom. Personalization in computer-based learning environments can similarly be achieved by enabling learners to express their uniqueness through color, style, or avatar choices. For instance, in a study using the online game World of Warcraft (WoW), Yee, Bailenson, and Ducheneaut (2009) found that avatars were judged by players to be more likeable or persuasive when they behaved or resembled the player. Enabling players to take on personas through personalized avatars leads to predictable behavioral and motivational changes. For example, Yee and Bailenson (2007) found that players attribute behaviors to their avatars according to the avatar's physical appearance and then perform to those expectations (see also Chap. 16, section "Exemplar 1: Promoting Avatar Design Through a Costume Contest").

Summary

The studies on the modality, signaling, contiguity, and personalization principles reviewed above highlight some important aspects for student learning. Overall, they appear to indicate that student engagement is increased through careful application of these multimedia principles to the design of learning environments. Further, there is some indication that students perform better on transfer tasks when these principles are applied. Finally, there is some question as to whether or not using these principles for design improves learning on post-task assessments. This situation raises some interesting questions, as the theory underlying these principles indicates that their use should improve learning. First, are the researcher rationales for the mixed findings in some studies valid or is there more to understand? Second, is it enough that these learning principles impact engagement and transfer but not short-term learning gains? For researchers and teachers interested in virtual worlds for learning, the results of these studies and the questions they raise provide a foundation for exploring the use of these principles in the design of virtual worlds.

Exemplars

Virtual worlds are touted as powerful for learning in large part because of their ability to mimic the complexity of real-world activities. Teachers like to use virtual worlds-based curricula because they are good at supporting the contextualized realism of learning tasks: Students learn by performing activities that look and act like their real-world counterparts, albeit in many cases with some of the non-pertinent material left out (Nelson & Ketelhut, 2007). This kind of experience is inherently complex and when embedded in a virtual world inevitably comes with a fair amount of what cognitive theorists might consider as extraneous cognitive load.

Early evidence shows that learners do experience high levels of cognitive load when interacting with educational virtual worlds. For example, in the River City virtual world project, middle school students reported not knowing where to focus their attention in the virtual world and described having difficulty in keeping track of the many sources of information encountered while exploring (Nelson, 2007). Such findings have led researchers to investigate whether or not virtual worlds can be made more powerful as platforms for K-12 learning and assessment through incorporation of multimedia principles that have a proven, though mixed, record of supporting learning in a different milieu.

Two research projects centered on the use of virtual worlds for middle and high school science education are exploring the use of multimedia design principles to reduce student cognitive load, bolster engagement, and increase learning. Although this area of virtual worlds research is too young to have produced true exemplars, the SAVE Science and SURGE projects offer useful examples of virtual worlds that incorporate elements of cognitive processing theory into the design of their curriculum and overall world design, and they offer insights to others designing or using virtual worlds in K-12 classrooms.

Exemplar 1: SAVE Science

The SAVE Science project is focused on creating and testing a virtual world-based model for assessment of middle school science learning for grades 7–8. Participants complete their regular, classroom-based science curriculum and then enter the SAVE Science virtual world (called Scientopolis) to complete assessment modules related to one or more aspects of the in-class curriculum. The project tracks and analyzes students' interactions in the modules as they complete them to evaluate how well they have understood the material taught in class. In the Scientopolis

Fig. 14.1 Visual signals in SAVE science

virtual world, students have an overall goal of uncovering the likely contributors to a series of problems facing a virtual city and surrounding countryside (sick farm animals, weather-related crop failure, and climate-related problems with the town's water). To accomplish the overall goal, students enter the virtual world multiple times over the course of a school year, conducting a new inquiry quest on each visit (Nelson, Ketelhut, & Schifter, 2010). Along with the main goal of evaluating student learning through an assessment curriculum designed with a situated learning perspective, researchers on the SAVE Science project have conducted a series of studies investigating the impact of multimedia design principles on cognitive load and engagement. Since SAVE Science is an assessment project, the impact of the multimedia design principles on learning cannot be assessed. However, other goals such as task completion rates pertinent to classroom assessment tasks have been examined.

Signaling Principle

In SAVE Science, the signaling principle is being applied through the use of visual pointers indicating which interactive objects in the world students can investigate as part of their assessment quest (Fig. 14.1). One sub-study within SAVE Science investigated the impact of visual signaling on perceived cognitive load and task completion rates in a virtual world-based assessment module (Nelson et al., 2010; Nelson, Kim, & Foshee, 2011). In the Sheep Trouble assessment module used in the study, interactive objects mainly consist of individual sheep from which students need to gather data to determine the differences between two distinct flocks of sheep.

Name: Original_A
Location: Downhill

Weight Loss: 25 Lbs

To save this to your notes, drag and drop on to Scitools.

Fig. 14.2 Measurements in SAVE science

Students can measure the weight, gender, age, and the lengths of various body parts of the sheep they encounter (Fig. 14.2).

In the signaling study, 193 seventh-grade students were randomly assigned either to a version of Sheep Trouble with visual signaling or a version without it. After finishing the module, students completed a cognitive load survey containing questions related to their perception of the difficulty they experienced in using the virtual world, including world navigation, object locating, data collection, and communication with in-world characters. The cognitive load survey was based on the one developed by Paas (1992) and included questions (see below for examples) through which students rated their own levels of mental effort in dealing with the virtual world and its curriculum.

A one-way analysis of variance (ANOVA) showed that students in the visual signaling group reported significantly lower overall cognitive load than those in the non-visual signaling group ($p < 0.05$). The effect of visual signaling was significant on the question “How hard did you have to work to communicate with people you met in Scientopolis?” ($p < 0.05$). Non-significant differences were seen on two additional questions: “How hard did you have to work to find things in Scientopolis you wanted to interact with?” ($p = 0.09$) and “How much effort did you have to invest in order to navigate in Scientopolis?” ($p = 0.07$). In all cases, students in the visual signaling group reported lower levels of perceived cognitive load.

For the task completion rates question, a tally of interactions with curriculum-related objects in the virtual world was automatically recorded. Results showed that students in the signaled version of the world showed significantly more interactions with in-world objects overall ($p < 0.05$), more interactions with sheep ($p < 0.01$), more measurements taken from the sheep ($p < 0.001$), and more records entered into the students’ electronic notebook ($p < 0.001$). Thus, it appears that use of the

Scientopolis : Recorded Measure (Name: Original_A)

Weight Loss : 25 Lbs

Body : 60 inches

Ear : 3 inches

Leg : 20 inches

Fig. 14.3 The module environment with “Roll Over” functionality

signaling principle allowed students to spend more time on items crucial to solving the problem presented in the virtual world, giving them a greater chance of successfully completing the assessment task.

Contiguity Principle

To apply the contiguity principle to the SAVE Science virtual world, a “rollover” function was developed and implemented. This function allows students to view their recorded measurements of in-world objects by rolling the mouse over any object from which measurements have already been taken. For example, when a student rolls his/her mouse over a sheep in the Sheep Trouble module, a floating window showing any recorded measurements appears in the top right corner of the module, near the sheep (Fig. 14.3).

A SAVE Science study investigated whether or not use of the contiguity principle as implemented via the rollover function would help reduce learners’ perceived cognitive load. Typically, students in the Sheep Trouble module retrieve information that they gather and record about the sheep in the virtual world by viewing text entries in an e-notebook (Fig. 14.4). Recorded items are listed in the order they were recorded, and depending on how many sheep a student has examined, these notes can be difficult to unpack.

In the contiguity study, 171 seventh-grade students were randomly assigned to a version of the virtual world with rollover functionality or to a version without it. Since recorded measurements and the related in-world object (i.e., the sheep) are visually integrated, the study hypothesized that students in the rollover treatment


Scientopolis: Note - Scale

Weight Loss : Original Sheep

Name	Loss	Location
Original_A	25 lbs	Downhill

Weight Loss : New Sheep

Name	Loss	Location
New_B	152 lbs	Downhill

Fig. 14.4 The module environment without "Roll Over" functionality

would not need to expend mental effort trying to match recorded measurements to in-world sheep, and thus would report lower levels of cognitive load. All students completed a post-implementation self-report cognitive load survey. The 10-point Likert-scale survey included questions based on those used in a previous study (Cierniak et al., 2009). The survey items included difficulty ratings on understanding the virtual world content, collecting/analyzing information, working in the virtual world, etc.

The study found no significant difference in perceived cognitive load between students using the rollover module and those using the control module. One explanation for the result could be the lack of specific instructions telling students to record measurements taken from sheep in their e-notebook and then to match those measurements with related sheep in the virtual world. In other words, the recorded notes and the related sheep were not presented as central components of the assessment task, although they are highly germane to solving the problem presented in the world. Since the need to make use of text and related visuals was low (at least as it related to the rollover functionality), no reduction in cognitive load related to integrating information between text and related in-world objects was seen. Future studies, however, are planned to investigate whether or not students with the rollover capability were able to solve the problem at a higher rate since they could visually associate sheep and related text simultaneously, making patterns easier to identify.

Personalization Principle

Use of the personalization principle was achieved in SAVE Science by including a function that allowed players to modify the appearance of their avatar (Fig. 14.5)

Use the buttons to customize your avatar. When you are done, click the 'Done Customizing' button.

Fig. 14.5 Customization treatment

Oh, Celestine! I hope you are in time to help!

Fig. 14.6 Customization conversation

and choose a name for their avatar from a list (Fig. 14.6). The names chosen were then used in in-world text-based conversations with characters.

A SAVE Science study investigated the impact of the personalization principle as implemented through these two approaches on student motivation, perceived performance, and engagement in virtual worlds. The study was conducted with 122 seventh-grade students. Data were collected from pre- and post-surveys and from in-world interactions. The pre-survey questions centered on gathering information about intrinsic and extrinsic motivation as well as students' need to personalize.

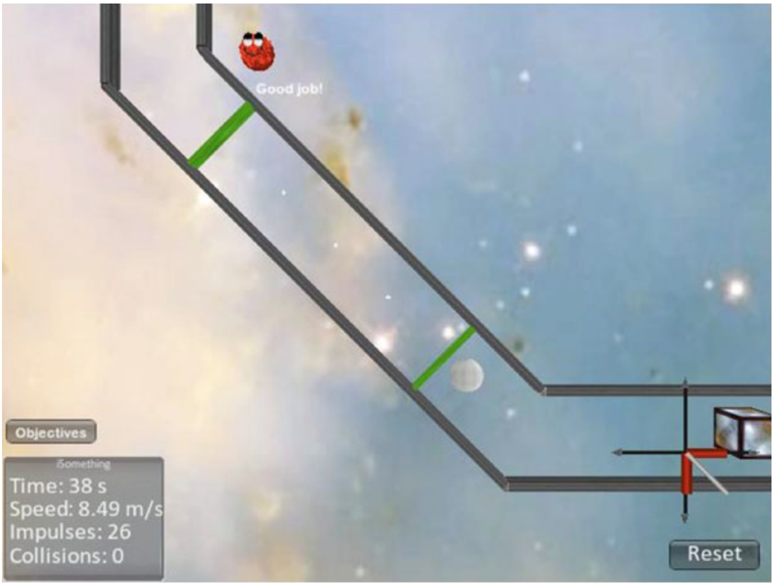
For this study, the intrinsic and extrinsic motivation were evaluated from students' ratings on a scale of 1–5, with 1 being strongly disagree and 5 strongly agree, on statements, such as "I have a real desire to learn science" and "One of my goals in class is to learn as much as I can," respectively. The *need-to-personalize* was defined as the degree of importance the students attach to personalizing objects in their own lives and the frequency with which they personalize such items. For example, students were asked, "Do you personalize your phone, other electronic devices, or backpack?" The post-survey questions focused on personalization-related motivation, perceived performance, and engagement. Perceived performance was evaluated from students' ratings on a scale of 1–5 (1 = definitely not and 5 = definitely yes) on questions, such as "Was your overall performance better than you expected?" Engagement was measured by recording the number of times students interacted with objects, tools, or characters in the virtual world and by students' ratings of the degree to which they felt they were part of the virtual environment. To this end questions like, "How often did it feel as if someone you saw/heard in Scientopolis was talking directly to you?" were asked and rated on a scale of 1–5 with 1 being not at all and 5 being very much.

The personalization study was conducted in conjunction with the contiguity study, resulting in a very small personalization control group ($n = 15$). Therefore, multiple regression analyses were conducted using the personalization group only ($n = 82$). Results showed a statistically significant correlation between a student's perceived performance in the virtual world and the following factors: personalization-motivation ($p = 0.01$), engagement ($p < 0.01$), and need-to-personalize ($p = 0.02$). The relationship between learner perceived performance and interactions with in-world objects was not significant ($p = 0.75$). All motivation factors were significantly related to perceived performance ($p < 0.01$) with the personalization-related motivation factor explaining an additional 2 % of the variance between perceived performance and motivation. Motivation was significantly related to engagement ($p = 0.03$). However, personalization-related motivation did not significantly predict over and above intrinsic and extrinsic motivation ($p = 0.13$). Furthermore, there was no interaction in the relationship between perceived performance and the need-to-personalize.

Overall, these findings suggest that although application of the personalization principle in the virtual world was motivating and valuable to students, its inclusion did not translate into deeper levels of exploration or engagement. However, the findings also indicate that personalization can motivate students to persist in virtual world-based activities.

Exemplar 2: SURGE

Another project exploring the role of multimedia principles in the design of virtual worlds is SURGE (Scaffolding Understanding by Redesigning Games for Education). The SURGE project seeks to incorporate design elements found in



Time: 38 s
Speed: 8.49 m/s
Impulses: 26
Collisions: 0

Fig. 14.7 SURGE 2D game level

casual physics-based computer games into learning-based virtual worlds to help middle and high school students connect "gut-level" understanding of physics they gain through playing such games with more formalized concepts, visual representations, and vocabulary (www.surgeuniverse.com). The SURGE virtual world looks and plays like commercial physics games, but also includes more formal physics representations in the game environments. Game levels are designed and sequenced to simultaneously scaffold students' mastery of the game and physics concepts (Clark et al., 2009). Storyline elements incorporate key physics ideas. Players must think carefully about navigation decisions to manage their limited resources, avoid collisions, maximize fuel, and minimize travel time (Figs. 14.7 and 14.8).

SURGE studies conducted with middle school, high school, and undergraduate students have shown learning gains on pre-post physics concepts tests. For example, in a study involving 280 middle school students in the U.S. and Taiwan SURGE players saw significant learning gains from pre- to post-content tests ($p = 0.019$). Another study with 124 undergraduate students in the U.S. found similar overall learning gains from playing SURGE ($p < 0.01$).

Signaling Principle

In SURGE, the signaling principle was implemented through the use of simple visual signaling of on-screen text. In the SURGE game, players receive information about game objects as they work through levels (e.g., the mass and velocity of

Fig. 14.8 SURGE 3D game level

their ship). A study was conducted to examine the impact of visual signaling of on-screen text messages on perceived cognitive load and learning with undergraduate students. The main audience for the SURGE virtual world is 7th–12th grade students. Testing design principles with undergraduates, however, allows for rapid iterations of game design research to explore design ideas that can benefit SURGE as it is implemented with its target audience. In the signaling study, half of the participants were randomly assigned to a version of the game in which important on-screen text was signaled by visually flashing the text when it changed. The other students were not given signaled text. Study participants completed a physics concept pretest, played seven levels of the SURGE game, and completed a posttest that included self-report cognitive load measures, physics concept questions, and feedback questions. Cognitive load was measured by three self-report questions that were given immediately after students finished playing the game. This approach is based on the method developed by Paas (1992). Students were asked to rate how much mental effort the game and different aspects of the game required on an 11-point scale ranging from Very, very low (0) to Very, very high (10).

The study found no significant differences in learning gains between the students in the signaled group and those in the non-signaled group, although both groups saw learning gains on the physics concepts measure. The researchers speculated that the lack of findings might relate to SURGE being a “low information seeking” environment.

Unlike virtual worlds designed as inquiry spaces, players in SURGE do not need to explore the environment of the game, focusing instead on directing their player (a spaceship) from one point to another point on screen. Consequently, SURGE may not necessitate a large amount of visual searching, obviating the need for visual signaling.

Next Steps

As we have described, multimedia principles have shown positive, although mixed, benefits for cognitive load, learning, and engagement in the design of computer-based learning environments. But their applicability to the design of virtual worlds has been largely unexplored until recently. The studies we have highlighted in this chapter are too preliminary in nature for the virtual worlds to be called true exemplars. However, they can offer insight into the questions and issues that will drive future research and influence the use of virtual worlds in classroom settings. First, it appears that signaling and modality principles can be used in virtual world design to reduce the perceived level of mental effort learners experience as they complete embedded curriculum. Visual signaling applied to virtual worlds in which information seeking is not a key curricular task, however, may be unnecessary.

Second, visual signaling may boost task completion rates in virtual worlds by increasing the likelihood that learners will interact with objects relevant to the goals of the curriculum. A challenge for teachers and schools wishing to use virtual worlds as platforms for learning is that they are often viewed as being less time-efficient than more direct methods of instruction. Conversely, proponents of virtual worlds for learning tout their complex realism (which brings with it a reduction in time efficiency) as a fundamental strength. Teachers, designers, and researchers may want to explore this conundrum by investigating ways to use signaling to increase time efficiency of virtual worlds-based learning, while working to maintain students' sense of immersion in the worlds.

Finally, the virtual worlds studies described in this chapter have not found any additional impact on learning outcomes associated with inclusion of multimedia design principles in the worlds. Future studies will need to focus directly on this issue to understand why. Some researchers have suggested that the traditional pre/post-survey questions used in the studies are not a good match for the kind of learning taking place in the virtual worlds, and therefore, are not able to reflect changes in learning associated with incorporation of multimedia design principles (Erlandson et al., 2010). It may simply be that, while some multimedia design principles help to reduce a learner's cognitive load in virtual worlds, such a reduction does not correlate with improved learning. Unlike the more traditional, presentational learning environments in which multimedia principles have been shown to support better learning, virtual worlds may simply be a "different beast." However, it is important to remember that the more traditional multimedia principles research is equivocal on learning gains when looking for immediate gains, but showed positive gains on transfer tests. This aspect of learning has yet to be researched in virtual worlds and is an important area for future investigation.

What is the bottom line for teachers and administrators wishing to use virtual world-based curricula in the classroom? Two guidelines for choosing an appropriate virtual world and curriculum emerge from this nascent research. First, look for virtual world-based curricula that incorporate signaling design aspects that can help students locate important data "hot spots" without reducing their sense of immersion in the environment. Careful use of signaling can bolster student activity completion rates and may make virtual world-embedded tasks less onerous, while still maintaining a student-centered curricular perspective. Second, virtual worlds with embedded personalization should be chosen for their motivational impact. Although use of personalization did not impact engagement or exploration rates in the study reported here, its motivational benefits could help engage reluctant students.

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Chapter 15
Narrative-Centered Learning Environments: A Story-Centric Approach to Educational Games

James C. Lester, Jonathan P. Rowe, and Bradford W. Mott

The past decade has witnessed a growing recognition of the potential of digital games to deliver effective and engaging learning experiences. One particularly promising class of educational games is narrative-centered learning environments. *Narrative-centered learning environments* contextualize educational content and problem solving with interactive story scenarios. By embedding learning within narrative settings, such environments tap into students' innate facilities for crafting and understanding stories (Bruner, 1991; Graesser & Ottati, 1996; Polkinghorne, 1988). Narrative-centered learning environments provide meaningful contexts for problem-solving activities, which illustrate connections between theories and applications (Jonassen & Hernandez-Serrano, 2002). They also exhibit a natural capacity to foster engagement by tightly integrating pedagogy and narrative elements.

Several narrative elements such as believable characters, dramatic plots, and fantasy settings are instrumental for yielding high quality stories (Egri, 1960; McKee, 1997). Incorporating these narrative elements into educational stories shows promise for enhancing student motivation and engagement during learning. However, effective authoring of narrative elements is difficult. The authoring challenges are heightened when working in a new medium, such as interactive digital games. In order to enhance the likelihood that a narrative-centered learning environment will positively impact student motivation for learning, it is valuable to consider how motivational factors bear on design decisions involved in authoring characters, plots, and settings, as well as gameplay mechanics. Moreover, explicit consideration of motivational factors can guide analyses of the extent and nature of these elements in narrative-centered learning environments.

This chapter describes design issues and empirical findings about motivation in narrative-centered learning environments. In the next section, we provide

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J.C. Lester (✉) • J.P. Rowe • B.W. Mott
Department of Computer Science, North Carolina State University,
Raleigh, NC, USA
e-mail: lester@ncsu.edu; jprowe@ncsu.edu; bwmott@ncsu.edu

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background on educational games and narrative-centered learning, as well as brief descriptions of extrinsic and intrinsic motivation. This background provides the foundation for our work on designing narrative-centered learning environments for K-12 classrooms. In the following section, we introduce a narrative-centered learning environment that has been iteratively refined in our laboratory over the past several years, CRYSTAL ISLAND. The CRYSTAL ISLAND learning environment supports middle grade science education, and it features an interactive science mystery. After describing CRYSTAL ISLAND, we consider design implications for creating narrative-centered learning environments that promote intrinsic motivation. We also provide a short summary of recent empirical results about student learning and engagement that were found from observing student interactions with the CRYSTAL ISLAND environment. The chapter concludes with a description of next steps for the field. This final section is aimed at researchers and practitioners interested in creating narrative-centered learning environments, as well as incorporating them into classrooms.

Background

As digital games have become ubiquitous sources of entertainment among children and adults alike, significant attention has been directed toward appropriating the best features of games and transferring them to educational settings (Gibson, Aldrich, & Prensky, 2007). Even the harshest critics acknowledge that games can be engaging, and there is mounting evidence that games offer significant potential for learning. It is widely believed that commercial games such as Civilization, SimCity, and Spore offer some educational value, and recent large-scale deployments of educational games have yielded promising findings (Barab, Gresalfi, & Ingram-Goble, 2010; Ketelhut, Dede, Clarke, & Nelson, 2010). Efforts to design serious games, which harness commercial game technologies for training, have been the subject of increasing interest in the defense community and industry (Johnson, 2010; Prensky, 2001). In parallel, recent years have seen the emergence of theoretical and epistemological foundations for educational games (Aldrich, 2004; Gee, 2003).

A key feature of state-of-the-art digital games is rich, immersive stories. Stories lend meaning to activities undertaken by players in game worlds. Digital games' emphasis on interactive stories is indicative of the pervasive presence of narratives throughout human communication and culture. Graesser and Ottati (1996) argue that "stories have a privileged status in the cognitive system" (p. 123), citing experimental findings that suggest readers process narrative texts more quickly and recall narrative information more readily than expository forms. Although stories are often associated with entertainment, they also serve a critical role in enhancing learning and problem solving (Jonassen & Hernandez-Serrano, 2002). Stories are ubiquitous tools for sharing experiential knowledge, recounting prior problem solutions, and fostering vicarious experiences. Additionally, stories are instrumental in assessment by virtue of their ability to present novel situations to test transfer of generalizable skills.

Interactive narrative is the cornerstone of narrative-centered learning environments. By incorporating advances from intelligent tutoring systems, intelligent virtual agents, and commercial games, narrative-centered learning environments present opportunities for creating adaptive, situated learning experiences that are highly motivating to learners (Aylett, Louchart, Dias, Paiva, & Vala, 2005; Johnson, 2010; Mott & Lester, 2006; Thomas & Young, 2010). Narrative-centered learning environments have integrated a diverse range of educational objectives, such as teaching negotiation skills (Kim et al., 2009; Traum, Marsella, Gratch, Lee, & Hartholt, 2008) and foreign languages (Johnson, 2010), through story-driven interactions with virtual characters. Also, scientific inquiry has been realized in interactive mysteries where students play the roles of detectives (Ketelhut et al., 2010).

Interactions with narrative-centered learning environments can take several forms. Students may directly influence a narrative by completing actions to solve a problem or they may indirectly influence events by providing guidance to autonomous virtual characters. Narrative-centered learning environments have been developed to support both single and multiple players, they have been realized using realistic 3D graphics engines as well as abstract cartoon-like representations, and they have structured problem-solving activities within overarching narratives, as well as sequences of related vignettes. Across these variations, the key unifying characteristic among narrative-centered learning environments is their tight integration between interactive narrative, educational content, and pedagogy.

Case Studies of Narrative-Centered Learning Environments

Two successful examples of deployed narrative-centered learning environments are River City and Quest Atlantis. River City is a multi-user virtual environment aimed at improving middle school students' deep inquiry skills and science content knowledge (Ketelhut, 2007; Ketelhut et al., 2010). River City's narrative takes place in a late nineteenth century city, where its residents have mysteriously fallen ill. Students control in-game avatars and work in teams to explore the virtual city, collect clues and evidence concerning the mysterious illness, formulate and test hypotheses, and compare research findings. Science content is integrated with historical, social, and geographical content.

Over the past decade, the River City software has been used with tens of thousands of students throughout the U.S. In a series of studies involving more than 2,000 students, the research team observed positive learning gains among students interacting with River City (Ketelhut et al., 2010). The observed learning gains exceeded those achieved by students in a paper-based control condition with the same pedagogy. However, this finding was not replicated in two subsequent implementations, suggesting the need for further investigation. In related studies, the research team observed promising trends in that students' inquiry behaviors increase in quantity and diversity over multiple exposures to the software (Ketelhut et al., 2010). Furthermore, Ketelhut (2007) obtained preliminary evidence that interacting with River City might help undo initial differences in in-game inquiry behaviors among high and low self-efficacy students. These findings point toward narrative-centered learning environments' promise for fostering motivation and scientific inquiry, although additional work remains to investigate their potential for promoting content learning.

As a second example, Quest Atlantis is a narrative-centered, multi-user virtual environment that has been used by over 50,000 students internationally (Barab et al., 2010; Hickey, Ingram-Goble, & Jameson, 2009). The virtual learning environment features a complex storyline about the fictional world of Atlantis. The Atlantians' planet is in rapid decline, and students must help to restore lost Atlantian knowledge that has precipitated the world's social and environmental decay. Gameplay activities are distributed across several virtual worlds. The virtual worlds feature distinct problem-solving scenarios that connect to national and local academic standards. For example, the Taiga Park world focuses on a riverside community with a declining fish population (Hickey et al., 2009). In Taiga Park, students complete a series of quests that incorporate socioscientific inquiry and ecological science concepts, incrementally addressing the community's looming ecological and economic dilemma. Students interact with virtual characters, collect and analyze data, and write and submit reports to improve the quality of the river.

Quest Atlantis's educational effectiveness has been investigated for several academic subjects, including middle school science (Hickey et al., 2009) and language arts (Barab et al., 2010; Warren, Dondlinger, & Barab, 2008). Empirical studies with a range of elementary student populations found that interactions with Quest Atlantis yielded significant learning gains on both proximal and distal test items, although the learning gains were statistically no different than traditional, text-based comparison treatments (Hickey et al., 2009). In another study, the research team observed substantial motivational benefits of Quest Atlantis compared to a comparison condition. The study examined a writing-focused version of the software, and the results suggested that students who played Quest Atlantis completed significantly more voluntary writing exercises than students in a face-to-face instruction comparison condition (Warren et al., 2008). While these findings are promising, it should be noted that neither of the studies were randomized controlled experiments.

The narrative-centered learning environment that is the focus of the current chapter, CRYSTAL ISLAND, was explicitly designed to foster content learning gains and intrinsic motivation for a curriculum that is aligned with state educational standards. Intrinsic motivation has previously been shown to positively impact student learning outcomes (Cordova & Lepper, 1996). Identifying factors that contribute to intrinsic motivation provides a foundation for formulating design guidelines for creating effective and engaging narrative-centered learning environments, as well as a theoretical framework for assessing the environments empirically.

Motivation

Motivation is a powerful force: it drives humans to act (Schunk, Pintrich, & Meese, 2007). Two types of motivation have been studied extensively: extrinsic and intrinsic motivation. *Extrinsic motivation* refers to engaging in a behavior because of external influences, such as tangible rewards or pressures (Ryan & Deci, 2000). Extrinsic motivation does not stem from one's internal interests. Instead, extrinsically motivated behavior can often be attributed to acting for the reward of pleasure or security manifested by something other than the task itself. Intrinsic *motivation* refers to engaging in a behavior because it is inherently interesting (Malone, 1981; Malone & Lepper, 1987; Ryan & Deci, 2000). The behavior is undertaken solely for the challenge it poses, the enjoyment it yields, or the curiosity it satisfies; the act has some internal utility. Intrinsic motivation is favored because it has been associated with quality learning and creativity (Ryan & Deci, 2000). Further, it is believed that pedagogy that cultivates interest in a subject matter is more likely to lead to self-initiated learning beyond instructional experiences (Bandura, 1997).

Malone and Lepper (1987) outline a taxonomy of intrinsic motivators that consists of both individual and interpersonal factors. We focus on the four individual intrinsic motivators: challenge, control, curiosity, and fantasy.

- *Challenge:* Tasks that are too easy or impossibly difficult will foster little or no intrinsic interest and may lead to student boredom or frustration, respectively. Designing optimally challenging tasks will enhance student motivation.
- *Curiosity:* Student interest can be maintained by controlling for an optimal level of discrepancy between the student's current knowledge and skills and the expected knowledge and skills following engagement in particular activities.
- *Control:* Humans have a basic tendency to desire a hand in their own fate. Providing mechanisms that allow students to manipulate the learning experience results in a sense of power and choice.
- *Fantasy:* Playing to students' abilities to develop mental models of situations that are not present contributes to motivation. Fantasies can evoke each of the other intrinsic motivators in ways that otherwise are unavailable to the student in reality.

These four intrinsic motivators can be realized in a number of forms within narrative-centered learning environments. In the next section, we describe a narrative-centered learning environment that was designed with the four intrinsic motivators in mind. We summarize several design decisions about how the motivators were implemented in the narrative environment, as well as empirical findings about the environment's instructional and motivational effectiveness.

Exemplar: CRYSTAL ISLAND

For the past several years, the authors and their colleagues have been designing, implementing, and conducting empirical studies with CRYSTAL ISLAND (McQuiggan, Rowe, & Lester, 2008; Mott & Lester, 2006; Rowe, Shores, Mott, & Lester, 2011).

Fig. 15.1 Screenshot of the CRYSTAL ISLAND narrative-centered learning environment

CRYSTAL ISLAND (see Fig. 15.1) is a narrative-centered learning environment built on Valve Software's Source™ engine, the 3D game platform for Half-Life 2. CRYSTAL ISLAND features a science mystery set on a recently discovered volcanic island. The curriculum underlying CRYSTAL ISLAND's science mystery is derived from the North Carolina state standard course of study for eighth-grade microbiology. CRYSTAL ISLAND's premise is that a mysterious illness is afflicting a research team stationed on a remote island. The student plays the role of a visitor who recently arrived on the island to see her sick father. However, the student gets drawn into a mission to save the entire research team from the spreading outbreak. The student explores the research camp from a first-person viewpoint and manipulates virtual objects, converses with characters, and uses lab equipment and other resources to solve the mystery. As the student investigates the mystery, she completes an in-game diagnosis worksheet to record findings, hypotheses, and a final diagnosis. This worksheet is designed to scaffold the student's problem-solving process, as well as provide a space for the student to offload any findings gathered about the illness. The mystery is solved when the student submits a complete, correct diagnosis and treatment plan to the camp nurse.

To illustrate the behavior of CRYSTAL ISLAND, consider the following situation. Suppose a student has been interacting with the virtual characters in the story world and learning about infectious diseases. In the course of having members of the research team become ill, she has learned that a pathogen is an agent that causes disease in its host and can be transmitted from one organism to another. As the student concludes her introduction to infectious diseases, she uncovers a clue while speaking with a sick patient that suggests the illness may be coming from food items the sick scientists recently ate. Some of the island's characters are able to help identify food items and symptoms that are relevant to the scenario, while others are able to provide helpful microbiology information. The student discovers through a series of tests that a container of unpasteurized milk in the dining hall is contaminated with bacteria. By combining this information with her knowledge about the characters' symptoms, the student deduces that the team is suffering from an *E. coli* outbreak. The student reports her findings to the camp nurse, and they discuss a plan for treatment.

Motivational Design Issues for Narrative-Centered Learning

The design of narrative-centered learning environments demands careful consideration of the factors promoting student motivation. Exploiting various motivational features during a narrative learning experience can influence factors, such as student focus and depth of involvement (Parker & Lepper, 1992). As noted above, challenge, curiosity, control, and fantasy are key factors affecting intrinsic motivation (Malone & Lepper, 1987). We consider how narrative-centered learning environments can address each factor and illustrate with examples from CRYSTAL ISLAND.

Challenge

Theories of intrinsic motivation suggest that humans often equate objectives that are challenging with those that are meaningful. Overcoming a challenging task provides a student with a personal sense of achievement and a test of her abilities. Challenge depends on student characteristics such as efficacy, prior knowledge, and skills as well as inherent task difficulty. Maintaining optimal levels of challenge throughout a learning experience is important. Excessively low-challenge periods may cause the student to feel bored, but high-challenge periods may bring about frustration and feelings of hopelessness. Incorporating intelligent tutoring systems and interactive narrative models provides a promising technological route for dynamically tailoring challenge levels to individual students. Investigating intelligent tutoring systems and interactive narrative models is a key element of the research agenda we are undertaking with the CRYSTAL ISLAND learning environment (Mott & Lester, 2006).

Pedagogical and narrative goals serve as natural embodiments of challenge in narrative-centered learning environments. Pedagogical goals generally surface as tasks that reveal information to be learned or provide problem-solving experience. Narrative goals involve interactions that advance the plot. The exploratory learning structure of CRYSTAL ISLAND is goal-based, unifying pedagogical and narrative goals into singular objectives that drive the experience. The learning environment utilizes fixed goals and emergent goals, as well as short- and long-term goals, in defining the interaction. Fixed goals are specific, system-dictated objectives that may be assigned by a virtual character or appear on screen through a heads-up display. Examples of fixed goals include “Speak to the camp nurse” or “Run a laboratory test on the milk container.” These are short-term goals for the student that can be accomplished by performing a well-defined sequence of actions. In contrast, emergent goals are student-defined tasks that arise as a function of the narrative path chosen. Interactive narrative environments, such as CRYSTAL ISLAND, permit several paths to progress through the story, each of which may be supported by different plot points and realizations of pedagogical objectives. One interaction may compel the student to find and test a banana for contamination, whereas a separate interaction may not involve bananas at all. These goals emerge from the student’s chosen path through the story. Finally, long-term goals in CRYSTAL ISLAND arise through complex multi-step objectives posed to the student, such as “Solve the mystery” or “Cure the sick patients.” Long-term goals provide a driving force behind the story and serve as a baseline motivator.

Uncertainty is useful in conceptualizing optimal goal challenge. At a given time, the student should be unsure about whether she will accomplish a goal or fail. This unpredictability provides an incentive to attempt a goal, coinciding with an innate desire to test one’s own abilities (Malone & Lepper, 1987). The mystery-based plot of CRYSTAL ISLAND provides a deliberate embodiment of goal uncertainty, incorporating variable goal locations and difficulty levels. The interaction also begins with the student having no knowledge of the epidemic’s cause, nor any sense of whether the mystery can be solved. Gradually revealing secrets underlying the mystery drives the entire experience.

Performance feedback and student self-esteem also influence a student’s perceived challenge. The characters of CRYSTAL ISLAND manipulate student perceptions of challenge through dialogue in which characters demonstrate or hint at the level of difficulty for a particular task. Capitalizing on the task-oriented nature of CRYSTAL ISLAND, models of affect (Lee, McQuiggan, & Lester, 2007) are likely to aid in understanding the affective responses to student appraisal of goal progression. For example, affect models can detect student frustration indicating that the challenge level may be too difficult. The student’s experience can then be adapted, perhaps through character acknowledgement of the task’s difficulty or comments on the student’s expended effort. Further, models of student efficacy (McQuiggan, Mott, & Lester, 2008) may provide useful insight into a student’s perceived challenge level through recognition of self-beliefs about the ability to manage the task at hand.

Curiosity

Curiosity is inherently motivating. It is typified by an individual’s drive to explore and discover some unknown subject, a desire that exemplifies motivation. Narrative introduces additional sources for evoking curiosity beyond the core subject matter.

However, narrative-centered learning environments must be carefully designed so that story-centric curiosity does not detract from learning objectives. A balance must be struck between narrative elements that contribute to the richness of a story world and elements that introduce seductive details. In CRYSTAL ISLAND, we have observed the best results with a streamlined mystery narrative that incorporates enough elements to create a coherent and believable story scenario, but does not introduce extraneous plot twists or characters that have no bearing on the overall problem-solving task. For example, previous versions of CRYSTAL ISLAND included a poisoning scenario that was intended to heighten drama and enrich characters' personalities. Although preliminary findings suggested that these additions contributed to engagement in the narrative, they did not appear to contribute to engagement in the game's educational objectives (McQuiggan, Rowe, Lee, & Lester, 2008). We observed that the extraneous narrative elements were associated with diminished student learning gains, perhaps as a result of the additional time that the elements occupied or cognitive load they imposed (see Chap. 14, Background, for design principles to reduce cognitive load). As a consequence of this investigation, we typically adhere to the following design heuristic: narrative elements are only included if they directly contribute to the immersive quality of the story world or invoke curiosity or meaning-making for an explicit educational objective.

Curiosity involves both sensory and cognitive influences (Malone & Lepper, 1987). Sensory curiosity is triggered through appeals to students' senses such as esthetic visual design, dramatic lighting, and enticing sounds. CRYSTAL ISLAND promotes sensory curiosity through its use of rich graphics, physics, and behaviors for the surrounding world. Nonplayer characters are realistically rendered with high-polygon models and realistic animations. The surrounding world is realized with authentic-looking lighting, detailed landscapes, and atmospheric sound effects. This high-fidelity experience provides strong sensory stimuli.

In contrast, cognitive curiosity centers on the desired modification of cognitive forms into well-formed structures like narrative completeness, consistency, and parsimony (Malone & Lepper, 1987). A student will pursue a subject in hopes of removing incompleteness and inconsistency from her understanding. Again, this is concretized in CRYSTAL ISLAND's science mystery, where students have an incomplete understanding of the elements responsible for the research team's illness. The spreading disease is inconsistent with a student's desire that the team members should be healthy, instigating a desire to solve the mystery.

Control

Control is one of the major tenets of interactive narratives, such as CRYSTAL ISLAND. Interactive narratives are explicitly intended to produce story experiences that react to a student's decisions and actions. The student's influence on the developing story reinforces feelings of competence and self-determination, both of which contribute to intrinsic motivation (Deci & Ryan, 1985). Similarly, perception of control, in contrast to actual control, is an integral motivational factor (Malone & Lepper, 1987).

Responsiveness, choice, and power contribute to a student's sense of control in narrative-centered learning environments. Nearly all events in CRYSTAL ISLAND are contingent upon student actions; when a student approaches a door and presses the "Use" key, the door perceivably opens; when a student approaches a nonplayer character and engages in a multimodal conversation, the character will respond appropriately with speech and gesture. The environment responds to student actions in clear and observable ways. This seemingly simple behavior is imperative for fostering a sense of responsiveness and power. Furthermore, students are free to choose how to navigate the world, interact with the environment, and solve the mystery. This flexibility is intended to provide students with a strong sense of choice, similarly advancing feelings of empowerment and motivation.

Fantasy

Narrative-centered learning environments use virtual settings and characters, which makes them an ideal platform for incorporating fantasy elements into learning. Fantasy has previously been shown to significantly influence motivation in elementary school students (Parker & Lepper, 1992). However, designing environments without considering both audience interests and fantasy themes can actually be detrimental to intrinsic motivation (Malone & Lepper, 1987). In designing CRYSTAL ISLAND, we have aimed to develop a fantasy setting that is sufficiently exotic to evoke broad interest, but recognizable enough to avoid confusion or distraction from the educational task.

Endogenous, emotional, and cognitive factors contribute to fantasy as an intrinsic motivator (Malone & Lepper, 1987). Endogenous fantasy refers to a bi-conditional relationship between the skills being learned and the fantasy supporting learning. Variation of pedagogical components must be accompanied by modification of the fantasy, and vice versa. This contrasts with exogenous fantasy, where the context depends on the skills being learned, but the skills do not depend upon the fantasy. The fantasy inherent in CRYSTAL ISLAND is endogenous. One of the primary objectives for the environment is learning through exploration and the scientific method, which is central to the actions necessary for solving the mystery. Removing either the mystery elements or the exploratory elements of CRYSTAL ISLAND would change both the pedagogical and narrative content of the experience.

Fantasy can elicit emotional reactions in students that support enhanced intrinsic motivation. Narrative context introduces opportunities for vicarious, affective experiences such as fame, adventure, and intrigue. Story worlds may also introduce nonplayer characters with which the student may identify and potentially develop empathetic relationships. CRYSTAL ISLAND's remote island environment, its empathetic characters, and the mysterious, spreading illness were designed to elicit emotional reactions, thereby influencing intrinsic motivation. Models of student affect (Lee et al., 2007) might also be used to influence narrative and pedagogical planning, ideally enhancing student motivation in real-time.

Impact on Motivation and Learning

Over the past 5 years, more than 1,500 students have interacted with CRYSTAL ISLAND through a series of studies that have been used to iteratively refine the learning environment. For example, a recent study (Rowe et al., 2011) investigated the relationship between learning and engagement in game-based learning environments. The investigation explored questions in the science education community about whether learning effectiveness and engagement are synergistic or conflicting in game-based learning. The study related to concerns that, on the one hand, students interacting with a game-based learning environment may be engaged but unlikely to learn, while on the other hand, traditional learning technologies may promote learning but provide limited engagement.

The investigation used data from a study involving over 150 middle school students interacting with CRYSTAL ISLAND. For the study, students entered the study room having completed a majority of prestudy test materials 1 week prior to the intervention. The prestudy materials included a content test comprised of 16 multiple-choice questions about relevant microbiology concepts. Upon entering the study room, students were provided with general details about CRYSTAL ISLAND and the game's controls through an introductory presentation. After the presentation, students completed the remaining prestudy materials and received several CRYSTAL ISLAND supplementary documents. These materials consisted of a CRYSTAL ISLAND backstory and task description, a character handout, a map of the island, and an explanation of the learning environment's controls.

Students were given 60 min to work on solving the mystery. Immediately after solving CRYSTAL ISLAND's science mystery, or after 60 min of interaction, participants completed a poststudy content test and several poststudy questionnaires. The content test was identical to the prestudy content test. The poststudy questionnaires included a Perceived Interest Questionnaire (Schraw, 1997) and Presence Questionnaire (Witmer & Singer, 1998). The Perceived Interest Questionnaire consists of 10 Likert items that measure students' situational interest. The scale was adapted from a previous version (Schraw, 1997) that assessed interest in literary texts. The Presence Questionnaire consists of 32 Likert items that measure user perceptions of presence, which refers to the subjective experience of feeling transported into a virtual environment (Witmer & Singer, 1998). The Presence Questionnaire is widely regarded as a standard questionnaire for post-hoc subjective assessments of presence in virtual environments.

In addition to the poststudy materials, the CRYSTAL ISLAND environment recorded an in-game score that provided a quantitative assessment of students' progress and efficiency in completing the science mystery. In-game score served as a loose proxy for in-game engagement. Details about the in-game score's calculation have been previously described by Rowe et al. (2011). The number of in-game sub-goals that students completed was also logged and served as a measure of problem solving. Poststudy materials took no longer than 30 min for participants to complete. In total, sessions lasted up to 120 min.

An investigation of learning gains found that students answered 2.35 ($SD = 2.75$) more questions correctly on the post-test than the pretest. The effect was observed to be statistically significant. Rather than finding an oppositional relationship between learning and engagement, the study found a strong positive relationship between students' learning gains, in-game problem solving performance, and increased engagement (i.e., presence, situational interest, and in-game score). Partial correlations controlling for pretest score found significant relationships between microbiology post-test scores and two engagement-related measures: presence ($r = 0.25$, $p < 0.01$), and final game score ($r = 0.38$, $p < 0.01$). A subsequent linear regression analysis indicated that microbiology background knowledge, presence, and final game score were all significant predictors of microbiology post-test score ($R^2 = 0.33$, $F(3, 143) = 23.5$, $p < 0.001$). Similarly, a partial correlation analysis controlling for content pretest score found significant relationships between sub-goals completed and microbiology post-test performance ($r = 0.40$, $p < 0.01$) and presence ($r = 0.24$, $p < 0.01$).

Next Steps

Narrative-centered learning environments show significant promise for fostering positive learning gains while simultaneously promoting student motivation. Strong connections between narratives, educational games, and intrinsic motivation ground arguments that narrative-centered learning environments promote learning and engagement through the constructs of challenge, control, curiosity, and fantasy. These motivational factors underlie key design issues in creating narrative-centered learning environments that synergistically integrate learning and engagement. Over the past several years, we have actualized these designs through an iterative development process in creating CRYSTAL ISLAND, a narrative-centered learning environment for middle school microbiology. Empirical results from a study involving middle school students have shown that CRYSTAL ISLAND effectively integrates student learning and engagement. In the future, we will be expanding the scope and length of CRYSTAL ISLAND's curriculum and narrative, as well as enhancing the existing interactive narrative features that foster intrinsic motivation for scientific problem solving. To further understand the effects of narrative on motivation, we plan to investigate real-time diagnosis of student motivation and devise an expanded array of techniques to create adaptive narratives tailored to learning episodes of individual students.

Research on narrative-centered learning environments is still in its nascent stages, and fundamental questions about their design, effectiveness, and deployment will likely drive the field for the next several years. Identifying a set of design principles to guide the creation of effective narrative-centered learning environments will be especially critical; in the same sense that some digital games are more compelling than others, well-designed narrative-centered learning environments may yield superior learning and motivational outcomes than poorly designed systems. Systematically investigating narrative-centered learning environments for a broad range of subjects and contexts will also be essential for properly assessing the pedagogical potential of this novel class of educational tools.

Compared to paper-based methods and nonimmersive computer software, narrative-centered learning environments are relatively expensive to develop. Fortunately, these costs are rapidly dropping with advances in computing power, as well as improvements in development tools. Similarly, deployment costs are rapidly dropping with the emergence of web-based distribution technologies. As these costs continue to fall, it will be essential to devise an extensive empirical account of the effectiveness of narrative-centered learning environments, as well as how students interact with these systems. These investigations should combine randomized controlled experiments as well as design-based field studies. Along these lines, it will be essential to devise frameworks for effectively incorporating narrative-centered learning environments in a range of educational contexts, including both classrooms and informal education settings.

As narrative-centered learning environments move out of the laboratory and into schools, professional development resources will become increasingly valuable for teachers to be able to readily determine how to successfully implement narrative-centered learning environments in their classrooms. Teachers trained in the most effective use of narrative-centered learning environments will likely yield maximum pedagogical and motivational benefits for students. Further, it will be important to develop supplementary classroom materials that complement the core story experiences presented by narrative-centered learning environments, extending the motivational impacts of these systems in a cost-effective manner.

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Chapter 16
Creative Play in Virtual Worlds: Avatar Designs, Language Play, and Cheats

Deborah A. Fields and Yasmin B. Kafai

Virtual worlds have drawn the attention of many individuals because of the alleged opportunities to make anything and to be anyone (Ondrejka, 2008). The creative design opportunities in some virtual worlds like *Second Life* are certainly immense—people can re-build the Sistine Chapel, create floating buildings, and make highly imaginative avatars to represent themselves. Indeed, Ward and Sonneborn (2009) suggest that creating virtual objects in virtual worlds is a significant opportunity for multiple levels of creativity, from the very small (mini-c) creativity of expressing oneself in a new medium (like learning to make an avatar online) to (little-c) creativity producing parts (clothes, buildings, landscapes) that others are willing to purchase, to higher levels of creativity shown in the professional design of innovative products that blend existing ideas and new forms, pushing the boundaries of what has been considered possible.

Yet, recent writing on the subject suggests that creative opportunities in virtual worlds, especially those for children, are not equal. In a synthesis of recent literature on virtual worlds and social networking sites for children, Grimes and Fields (2012) report that literacy opportunities to read and write expressive texts are uneven across virtual worlds for children, especially compared with sites like the *World of Warcraft* that offer on average 12th grade reading level texts and wide opportunities for personal expression (Stienkuehler, Compton-Lilly, & King, 2010). In part, this is due to restrictive rules on player behaviors and interactions in the name of children's safety that limit what children can say in their chat and how much freedom they

D.A. Fields (✉)
College of Education and Human Services, Utah State University,
Logan UT, USA
e-mail: deborah.fields@usu.edu

Y.B. Kafai
Graduate School of Education, University of Pennsylvania,
Philadelphia, PA, USA
e-mail: kafai@gse.upenn.edu

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have to express themselves in other ways (see also Black, 2010; Carrington & Hodgetts, 2010). Grimes (2010) further found that a high presence of branded content and third-party advertisements often meant a tightly structured virtual world environment with heavy restrictions on available activities and few options for explorative play. In contrast, massive virtual worlds for teens and adults like *Second Life* include more liberal freedoms and creative tools. Grimes and Fields also point out that much of the designed game play in virtual worlds is socially limited to single-player games that often do not provide feedback for deeper learning (Black & Reich, 2011) or demand only a superficial level of interaction (Aschbacher, 2003). Although evidential research is just beginning to emerge, on the whole, there is a concern that opportunities for creative play in virtual worlds for children are often limited in scope.

Against this backdrop, we turn to both designed affordances for creativity and ground-up creative play developed by children in a comparably open virtual world for tweens (children on the cusp of adolescence, aged 9–13), Whyville.net. Compared to many virtual worlds for children, Whyville offers relatively free verbal expression through chat, many spaces where children can socialize with each other, and broad opportunities for designing avatars. These qualities make it an environment where we can look for exemplars of children's emergent, creative play. In particular, we attend to players' agency and design, considering where the most open-ended creative expression is encouraged and where children have played in ways not predicted or not condoned by the designers/authorities of the virtual world. Three key areas of activity—avatars, flirting, and cheats—provide promising contexts to examine youth's creative design and play since they capture the creative play the Whyville designers intended (avatars) and that which emerged from the children themselves (flirting and cheating), sometimes seen as transgressive forms of participation. Below we provide a brief background on creative design and play, arguing why we should attend both to socially sanctioned as well as potentially transgressive creative expression.

Background

In play with peers, children are free to experiment with rules and design their own pretend scenarios, characteristics that set the stage for creativity. Indeed, Vygotsky (1933/1978) points to pretend play as a formative area of development where children process the rules and roles of the culture around them as they playact scenarios that mirror real life cultural rules. For instance, Vygotsky provides an example of two sisters playacting at being sisters: the girls consider the "rules" for being a sister (doing everything alike, considering what is "ours" and what is "others") and how those are applicable in different situations: "the fact that sisters play sisters induces them both to acquire rules of behavior" (p. 95). Play thus brings together real actions in imaginary situations, allowing the child to be independent in exploring what it might be like to obey a particular rule system that is both based on reality and an imaginative scenario. This promotes children's learning of social and cultural practices.

In addition, Vygotsky (2004) sees imagination and creativity as emerging through combining things that we know into something new: combining and reworking elements of one's past experience and using them to generate new propositions and new behavior. This process applies both to designed products like drawings and written stories as well as to ideas that inform people's daily practices. By taking ideas from their own experiences—whether family rules about appropriate behavior or images from daily life—children create new things that can shape the thoughts of others around them. Elbers (1994) develops this idea further by suggesting that children's peer play is a space of creativity where children develop innovative social practices that reinterpret and press the culture around them. She argues that in this way new ideas come to society through play: "[c]hildren will not simply reproduce the adult culture: they will create something new, something of their own" (p. 234). This makes children's pretend play a site of cultural significance, for it is here where innovative ideas that may address existing cultures can emerge. Thus, everyday play involves creativity, not just designed products like art and music.

These conceptions of creative play lead us to see peer play as a promising area to find the "new" things that children are developing in imaginative interaction with peers. The areas of greatest freedom turn out to be socially acceptable and socially transgressive forms of tweens' creative play in Whyville. We consider avatar design as a form of creative expression provided by the designers of Whyville, a socially sanctioned activity that results in virtual looks created from a bricolage of face parts designed and sold by individual players. This activity is highly popular— nearly 30% of all players' activities are focused on avatar design (Feldon & Kafai, 2008). We also discuss an intervention we hosted in an after-school club to further stimulate children's creative design of avatars while promoting reflection on cultural values of particular looks. To broaden our scope, we turn to a peer-developed form of play allowed but not designed for by Whyville's creators: language play in flirting. In this form of creative play, players build on practices they have witnessed in their everyday lives and invent new forms of flirting that both imitate and innovate in this particular virtual world. Finally, we look to the edges of the virtual world of Whyville and even beyond the site itself to consider cheating as a form of transgressive yet creative form of play that pushes back on the intended culture of playing science games in Whyville, adding elements of collaborative agency to an otherwise single-player consumption of a game.

Virtual World: Whyville.net

With over 6.5 million registered players having an average age of 12 years, Whyville offers a broader audience than most educationally designed virtual worlds without the degree of consumerist focus of its commercial peers, thus avoiding some of the restrictions Grimes (2010) pointed out. It has both non-profit and commercial sponsors for its multitude of spaces and activities, from NASA to Toyota, and its developer, Numedeon, is focused on promoting science education. Interestingly, 68% of Whyville's players are girls, an unusually large percentage for an informal science learning community. A typical day in Whyville sees about 20,000 users log in to participate in over 10,000 science activities in visits that last anywhere from 5 mins to over 5 hrs, with an average login of over 30 mins. There are many design opportunities on Whyville, from assembling one's "face" (avatar) to creating face parts to sell to other citizens (this requires $5/month subscription), to designing a house, and to creating a commercial airplane contract bid.

Our research included two after-school clubs from a private elementary school in urban Southern California. Both clubs were visited by tweens ages 9–12 years (fourth to sixth grades) for an hour most days after school for 2–3 months each. Enrollment and visits to the club were voluntary and included 20 youth in the first club and 10 youth in the second club. Though we did not collect information about the individual students' backgrounds, the school was representative of the ethnic and socioeconomic diversity of California at large, and activities by individual students demonstrated the importance of displaying their ethnicity through avatar representations. Most students were able to log on to Whyville at home. Relevant data for this chapter include field notes, videos, and interviews for both clubs in addition to tracking and chat data across 600 participating online Whyvillians in Spring 2005 (for more information, see Fields & Kafai, 2012). The exemplars shared in this chapter draw on some of our prior research, including research documenting avatar creation and face part design tools available in Whyville (Kafai, Fields & Cook, 2010), research documenting numerical comparisons of face parts with different skin colors as well as social movements reported in the citizen-written *Whyville Times* to understand race in Whyville (Kafai, Cook & Fields, 2010), a study of Whyville cheat sites (Fields & Kafai, 2010), and an analysis of flirting practices in Whyville (Kafai, Fields & Searle, 2010). Details regarding the methodology and analysis can be found in the cited studies.

Exemplars

In this section, we first describe some of the broad affordances of avatar design in Whyville, including a specific intervention we hosted in a local after-school club to promote reflection and creativity in design. Then we consider creative language play in flirting followed by an account of cheat sites as transgressive design.

Exemplar 1: Promoting Avatar Design Through A Costume Contest

In Whyville, avatars are one of the broadest areas for creative play in the virtual world as well as one of the most important avenues for making friends in the world. Having a good look is a high priority for youth as it affects how others treat them.

Many Whyvillians make fun of newbies for their cheap face parts; gain entry into select hangouts through their goth, anime, or “black”/African-American looks; and use good looks to facilitate flirting. In Whyville, avatars are created by assembling “face parts” that citizens obtain through donations, purchases (shopping at Akbars Face Mall), or trading with others. Once they obtain face parts, Whyvillians go to “Pick Your Nose” to layer on the parts bricolage style, picking a head and positioning eyes, eyebrows, nose, mouth, hair, and clothing. Beyond the creative work involved in assembling face parts for one’s avatar, there are tens of thousands of face parts available in Whyville, which are created and sold by Whyvillians themselves. Players use the two-dimensional digital painting palette to draw parts, submit them for approval, and then produce and sell them. Though the design tool can be challenging to use, many have become popular (and wealthy) designers in Whyville (see Kafai, Fields, & Cook, 2010) with more than 600,000 face parts and 90 million sales of faces completed in the past 11 years. Of course, there are restrictions on what is an acceptable look from the designers of Whyville (waists are discouraged), from social peer pressure (do not put eyebrows above your hair!), and from what is available in the Face Mall if one does not design one’s own face parts. For instance, we documented a bias toward Caucasian skin color in the available face parts in 2006 that limited some Whyvillians’ choices in representing their ethnicity (see Kafai, Cook, et al., 2010).

In order to capitalize on the importance of avatar design in Whyville, we created an intervention in one after-school club to stimulate reflection on how people look. Midway through our 2008 after-school club, we held a week-long “costume contest” to encourage youth to experiment with a different kind of look. We started the contest after club members had spent enough time on Whyville to move past their newbie looks and establish recognizable, personally customized looks on Whyville, about 1 month into the club. The challenge was for the youth and adults to see who could come up with the look “most different” from what they had had before. Though they were reluctant to change the looks that had finally allowed them to set aside their newbie status, the members made some very creative designs: two boys became girls, one boy (Tyrone) moved from a newbie to an anime look, one girl moved from a put-together look to a collage of random face parts, and one girl (Lucetta) became an alien. In Fig. 16.1, we show Tyrone and Lucetta’s avatars before and during the contest. One can easily see the significant differences in how they looked before and during the contest.

After the contest ended, we solicited reflections on how the changes in their looks affected how Whyvillians responded to them. All of the youth explained that their new look affected how others interacted with them. Some gained popularity, others ridicule. Lucetta, in particular, stood out because of the intentionality with which she created an ugly avatar on Whyville: a green, snarling alien. All of her choices were by design: picking the green head, choosing a scary mouth, and deciding on an “old lady” outfit, and adding a hat, “Cuz she [her avatar] was so bald… Women don’t like to be bald.” In her alien design, she juxtaposed feminine features (the “old lady” dress, the wide-brimmed hat) with the snarling green alien. She purposefully chose these qualities to be original, “different than all the rest of them,” and the pictures in Fig. 16.1 demonstrate how different her avatar looks were, even

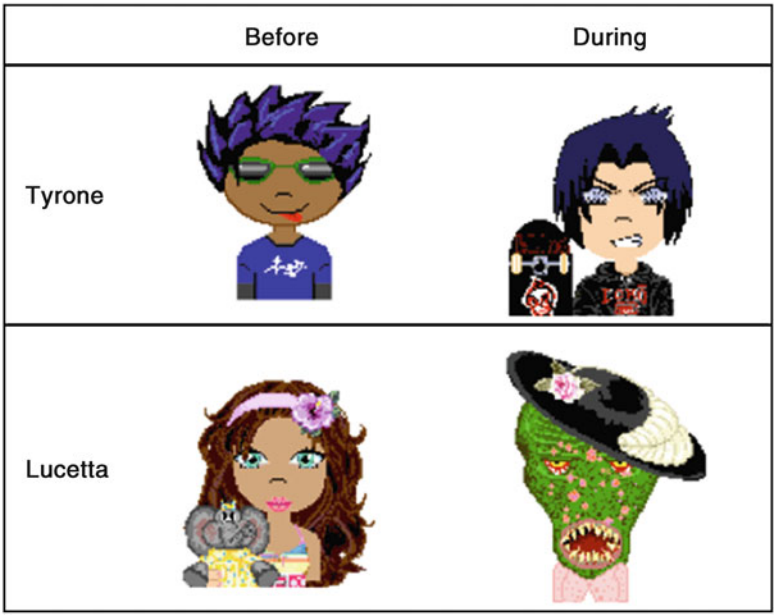

Fig. 16.1 Screenshots of youths' avatars before and during the costume contest

though they both involved purposeful, thematic choices that reflected her priority on fashion and her sense of what was attractive in Whyville. One look was attuned to what was beautiful in Whyville, and one daringly reflected what was ugly there.

Lucetta's alien avatar certainly influenced how others treated her in Whyville. She reflected afterwards:

Lucetta: It was odd, a lot of people were, some people were mean.
Deborah: Oh, like how?
Lucetta: Like I would go over and they'd um, some person went '555 if she's ugly,' and there's this whole bunch of people saying '555. 555.' Then I'm like 'Thank you!' *((perks up with high tone))* … Then they probably were surprised when I said 'thank you.'

After describing how others called her ugly and treated her meanly, Lucetta went on to say that one Whyvillian befriended her during that time period, but even then, he and others were more friendly when she went back to her earlier look. Other club members also reflected on how their avatar designs changed during the contest and how others treated them differently. Tyrone assembled a variety of face parts from different Japanese anime characters and found that some Whyvillians began to initiate conversations with him about a shared interest in particular manga. Another girl chose to put a mass assemblage of fun face parts together on her face and found that this caused others to interpret her as a newbie and to refuse to talk to her. After the contest, all but Tyrone happily went back to more traditional looks.

We hosted the after-school club for two reasons. First, we hoped to encourage reflection on how we interpret others by their looks. Often Whyvillians who were once ridiculed because of "newbie" appearance take up these same denigrative practices as soon as they become recognized insiders in Whyville, something that happened in our first after-school club. Second, Boellstorff (2008) has noted how many individuals do not take advantage of the great freedom of the avatar design tools in *Second Life,* most often mirroring their own physical appearance and responding to the social norms on the site. This contest was an initial attempt to stimulate youth to experiment creatively with some of the design opportunities in making avatars while reflecting on the social responses this generated.

Exemplar 2: Creative Language Play Through Flirting Performances

Alhough Whyville's creators built in broad affordances for avatar design, flirting was a form of play that children on Whyville invented. A widespread activity for many years on Whyville, we would argue that this is a kind of peer-created social game where Whyvillians play with the roles, rules, and ideas of flirting they draw from popular culture. For some, part of the game is seeing how many boyfriends or girlfriends they can collect. Another part of the game is trying different strategies to get boyfriends and girlfriends, something that may include practices like creative pickup lines, gifting romantic face parts (e.g., jewelry), and even paying clams (virtual money) to "hot" looking avatars. Of course, not all Whyvillians engage in flirting—many simply experiment with flirting for a short time period—and it is a hotly contested practice as written about by citizens in *The Whyville Times* (Kafai, Fields & Searle, 2010). It was certainly not a part of the designers' intentions for this virtual world, and thus it provides an interesting lens on the ways that youth press back on the intended design of a space.

We see examples of Whyvillians' creativity in the seemingly bizarre ways they have found to flirt in crowded virtual spaces with chat filters that limit some of their verbal expression (for more information, see Giang, Kafai, Fields, & Searle, 2012). Since making significant social contact with individuals can be difficult in a space populated by millions, they developed ways to massively solicit relationships. These methods include spamming pick-up lines in highly populated spaces, such as asking who is single ("r u single" or "123 if ur single"), soliciting someone's age/sex/location ("a/s/l"), and summoning positive affirmation for one's sexual appearance ("555 if im hot"). Similarly, to bypass the chat filters that bar words like "sex" or "sexy," Whyvillians creatively developed means of expressing these words in alternative ways, including using words like "sessy" and "sesky," adding spaces between letters as in "S E X Y," and having multiple avatars spell out parts of phrases in sequence as in "Se" "xy." In flirting, Whyvillians have found creative ways to transgress the "adult" rules about what is appropriate to say and do, developing innovative social performances that play with practices of flirting and dating they observe in their daily lives. Below we discuss more about transgression as creative play in our discussion of cheating.

Exemplar 3: Transgressive Cheat Designs for Knowledge Building

Whyvillians' use and development of cheats and cheat sites illustrate the role of agency in children's creative design where the goal is to work around the intended rules of the site. Cheats can help win mini science games, beat fellow Whyvillian competitors in a race, scam others out of their hard earned clams, bypass the chat filter, and provide cultural hints on what looks good on Whyville (see Fields & Kafai, 2010; Kafai & Fields, 2009). Cheat sites themselves are found outside of Whyville proper since they are discouraged on the site itself. That cheats are a prominent part of play and topic of discussion is evident in the over 100 articles published in the *Whyville Times* between 2000 and 2005, where authors debate whether or not and to what degree Whyvillians ought to use cheats. Officially, site designers do not condone cheats, but unofficially some have confessed that they find some cheats to races or science games creative. Below, we describe some of the types of cheats and cheat sites followed by one example of the collaborative process through which a "cheat" was created for a science game.

Although cheats may appear to be a way of bypassing intended learning in a science game, the design of cheats has the potential to engage children in science. The degree to which creating a cheat promotes learning depends on the quality of the game. For instance, at the most basic level, one must successfully play a game and write down a list of answers to create a cheat. Yet, some of the science games on Whyville are not beaten by entering a specific answer but through tweaking the design settings of a simulation, navigating an object through challenging winds, or throwing objects in specific ways. For these games, a list of answers will not suffice and instead a cheat must provide a guide for navigating a problem or a walkthrough of how a game should progress. In our analysis of cheats for Whyville games, we even came across examples with helpful reference guides, illustrations, and screenshots (see Fields & Kafai, 2010). Further, for one science game, the Spin Game, we found that the best solution involved theory development about making objects spin faster by lining them up vertically. Although the Spin Game is the only game on Whyville that encouraged such an explanation, we think it provides a positive model for designing games that will promote creative cheat design (Kafai & Fields, 2009).

Sharing cheats involves creative design in the form of cheat sites, websites that are set up separately from the actual virtual world. The design and production of the sites involve skills that range from creating a basic web page to including discussion forums, bulletin boards, advertisements, and other common web applets. Cheat sites we studied often included more than just collections of cheats for Whyville's salary-raising science games. They also uncovered secret places, unveiled glitches, provided walkthroughs of more difficult strategies, and even disclosed cultural insights on how to create a good look, where to shop, and how to make friends. Although the above sites were concerned with helping others to go deeper into the games and social world of Whyville, other sites engaged individuals in more unethical behavior by creating a broad range of scams to obtain others' virtual money through stealing passwords or making vacant promises. Some sites even went so far as to emulate official looking sites to reassure the visitor of their less than honorable intentions. Although these sites were not concerned with helping Whyvillians to have positive experiences on the site, we cannot ignore that they engaged in creative albeit unethical play by finding new ways to scam fellow citizens. This behavior is consistent with some studies that point to nonconformist youth online as having the highest skill sets and getting the most out of their (uncondoned) online activities (National School Boards Association, 2007). In our in-depth case studies of youths' creative play in Whyville, we found that the youth most deeply engaged in Whyville were the ones who had the knowledge and ability to scam others. However, the youth who did scam others did so only for a few weeks, leaving these practices in the long run (see Fields & Kafai, 2012).

A case study of one of the best cheat sites for Whyville, GameSite.net (a pseudonym), reveals players' considerable creativity in both designing websites and developing cheats. GameSite.net provided multiple cheat types for science games, in addition to other relevant cultural knowledge not intrinsic to monetary success on Whyville, as well as a forum to discuss appropriate behavior in Whyville. While many cheat sites merely listed the cheats, GameSite.net also provided a discussion forum for more active participation. The site owner and designer, a 14 year-old youth, and his three administrators posted new messages on the home page of the site roughly four times a month, not counting numerous responses to messages on the forums. Further, the owner closely watched forum postings for inappropriate material and advertising of other sites.

During our observations, we witnessed how the cheat site design team orchestrated community involvement in finding a cheat for a new salary-raising science game, the Spitzer Spectrometer. In the game, one had a limited amount of time to match the spectrum of a mystery element to one of a known element. When the new game appeared on Whyville, players had difficulty winning the game in the time allotted. Encountering these difficulties, the site owner posted the following message soliciting solutions:

> We have read up on Spectroscopy on the Internet and found nothing on it! Now since we can't figure the game out we need your help to give us the answers so we can give them to every one else. We will give the first person who responds [sic] to us with the correct answers **2000 clams!**

Many frustrated postings by Whyvillians followed, revealing discouragement in efforts to play the game. Finally, 1 week after the original plea, a girl came up with a clever, scientific solution, posted her solution online, and told the forum about her cheat. The cheat consisted of individual screenshots taken of each element's spectra and listed as a table, what one might consider a scientific reference guide similar to what professional scientists might use to discern what element's spectra they are observing. This cheat allowed players to shift from a strategy of trial and error to a more systematic and less time-consuming search of the reference table to correctly identify a mystery element's spectra. This example demonstrates how cheat design can be collaborative as well as scientific. After the members of the cheat site designed and published this cheat, Whyville's designers chose to make the game simpler, allowing more time to figure out the answers. This solution was ironic since the cheat designers had accomplished the same goal in a more scientific and creative manner. Instead of relegating cheats to the side, how might developers consider them in the design of games and virtual worlds? How can we sponsor creative practices in designed virtual spaces? Those are some questions that designers of virtual worlds may want to consider.

Discussion and Next Steps

In this chapter, we have sought to illuminate creative play found in the open-ended spaces of the virtual world of Whyville, namely in avatar design, language play, and cheats. These three areas highlight some of the intended (avatar design) and unintended (flirting, cheating) ways children play creatively in virtual worlds. With hundreds of millions of participants, virtual worlds for children and youth are still untapped and understudied for their educational potential. Grimes (2010) argued that these worlds—left vacant by game designers and educators—have been largely created and driven by commercial companies that use them for product placement and advertising, acculturating children to consumerist practices and constraining their personal expression in their social play spaces. With the idea that children's peer play is a significant place to look for innovation and creativity, we must consider how to make virtual world spaces that allow enough freedom for creative expression.

It is probably not a coincidence that most of the areas we highlighted as sites of creative play involved transgressions against the intended design of the virtual world. In their flirting and development of cheats and cheat sites, Whyvillians went beyond the design of their virtual world and even the space of the virtual world itself to work around the social and technical designs of Whyville. Significant opportunities for learning academically related skills are present in the designs of cheats and cheat sites in particular: technical skills from scripting to databases to web hosting; media skills in building a following and earning money through advertisement; science skills involving the use and creation of representations and explanations; and creative skills working around the technical designs of games, chat filters, and official social practices. As such, these transgressive designs (Kafai & Fields, 2009) provide a fertile learning context for leveraging game and virtual world design more explicitly for children's design purposes.

What would it mean for teachers and parents to encourage children in transgressive design? How can we provide opportunities to develop cheats for formal schooling and what might children gain from them? Consider the following scenario. A class playing together on a virtual world that has educational games (like Whyville) collaboratively develops their own cheat site. Students research answers, strategies, walkthroughs, reference guides, and whatever else is needed to solve the games. They also write up cultural guides for dressing appropriately, making friends, and finding secret places. Cheats could go first on a class bulletin board and later on a website that the class produces, adding digital literacy skills to collective knowledge building (Scardamalia & Bereiter, 1996) through cheat producing. This shifts children from consuming media in a virtual world to *producing* media and *evaluating* the world itself.

Of course, cheats are not solely relevant for virtual worlds or online games. Instead, consider the role of designing cheats for more typical classroom learning. Engeström (2008) encourages his students to cheat on tests by allowing a small slip of paper in the test situation. One of the most challenging aspects for students is selecting the most relevant information to put on their cheating slip and organizing it well enough that it is useable in the test environment. Engeström even collects these slips after the tests to gain insight into the thought processes of his students. What would cheats look like for an elementary language arts class? Perhaps students could come up with lists of excellent sentence starters, transition words, models of writing, or strategies for learning spelling and vocabulary. Utilizing cheat designs in formal classroom learning provides a provocative lens for students and teachers to use a metaphor from popular culture (cheating in games) to help students manage their own learning.

Cheats and cheating, developed by children themselves, may also encourage reflection on the design of games and virtual worlds. Reflecting on the design of a game does not commonly happen on its own. Shrier (2005) and Squire (2004) found that although players became adept at using and understanding rules of the games they played (including such games as *Civilization III* in a history class), the young people unquestioningly accepted the norms, ideologies, and means of representation in the games (cited in Jenkins, Purushotma, Weigel, Clinton, & Robison, 2006). Engaging children in understanding and challenging the built-in assumptions of games and virtual worlds may encourage them not simply to reproduce commercial media or negative social practices (e.g., making fun of newbies) but actively engage in creative design that disrupts such discourses (e.g., Kellner, 1995). The costume contest was an example of our own intervention that capitalized on an area of creative design and helped children reflect on the social pressures to look a certain way in Whyville. As a result of the contest, we saw how avatar designs provided alternative creations that went against the local social norms and promoted thinking about how they treated others.

Avatars provide a relatively easy opportunity to step into someone else's shoes by looking differently and by seeing how others react. Classroom teachers could enhance children's awareness of how perceptions may impact judgments made about someone by taking on different roles. For example, students in a social studies class could participate in a mock trial to develop argumentation skills and at the same time explore how the appearance of a defendant in the case (i.e., how s/he dresses, speaks, and reacts emotionally) may potentially cloud the jury's thinking. The children could reflect on the extent to which perceptions in other situations influence their impressions, reasoning, and decision making. We also need to seek out other opportunities that can promote children's reflections on the norms, value, and design of games and virtual worlds. In that sense, creating playful interventions that capitalize on the creative affordances of virtual sites is one way to do so. The overarching goal is to help students creatively understand and reflect on the social rules that shape their daily activities and to consider what it would be like to be in someone else's shoes.

In creating virtual spaces for children under the age of 18, developers face concerns of safety and protection when providing room for creative play. Researchers like Boyd (2007) have called virtual worlds, online games, and social networking sites "digital publics" because they provide a place for youth to gather and hang out with peers. Yet, despite these trends toward hundreds of millions of children playing in virtual settings, it is unclear to what extent they provide enough openness to support creative play, especially for children and youth. If as Jenkins (1998) has argued, spaces for peer play are being constrained by discourses of safety and protection year after year, how can we sponsor open areas where children can be imaginative in their play? With other major developments in communicative technology (telegraph, telephone) moral panics have often ensued as adults worry about children's safety and moral character because of the influences of new technologies (Cassell & Cramer, 2008). However, we must be careful not to make the issues about protection and avoidance, which belittle children's agency and design. Instead, virtual worlds need to provide opportunities for creative design and room for the development of innovative social practices amongst peers to sponsor learning and innovation.

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Chapter 17
Imagining, Creating, Playing, Sharing, Reflecting: How Online Community Supports Young People as Designers of Interactive Media

Karen Brennan and Mitchel Resnick

We recently hosted a workshop for a group of 20 teenage girls to introduce them to work that is done at the Media Lab and, more specifically, in our research group, Lifelong Kindergarten. At the beginning of the visit, we asked the girls how they were currently using computers. Almost all of them had used computers to connect with other people—getting and giving personal updates through a social networking site, like Facebook, or chatting with friends and family through an instant messaging service, like Skype. They had also used computers to connect with content—watching videos on YouTube, listening to music on Grooveshark, reading articles on Wikipedia, or playing games on Miniclip. However, other than using office productivity software to write papers or create presentations, the girls were not actively engaged in creating their own media let alone interactive media, such as games.

The girls' answers were not particularly surprising—most young people do not have opportunities to engage in the design or creation of interactive media. We shared that one of the goals of our research group is to enable a wide variety of people to engage in technology design activities. Whether it is making your own robot or making your own software, we think people have powerful learning experiences when they are able to connect their personal interests with the design of artifacts. We added that we develop tools that make those design experiences available to new audiences.

In the workshop, we gave the girls a hands-on introduction to one of the tools that our research group has been developing, called Scratch. Scratch (http://scratch.mit.edu) is a programming environment that makes it easy to create interactive media such as games, stories, and simulations. Unlike text-based programming languages (e.g., Java or C++), with which you need to type out programming instructions,

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K. Brennan (✉) • M. Resnick
Media Lab, Massachusetts Institute of Technology,
Cambridge, MA, USA
e-mail: kbrennan@media.mit.edu; mres@media.mit.edu

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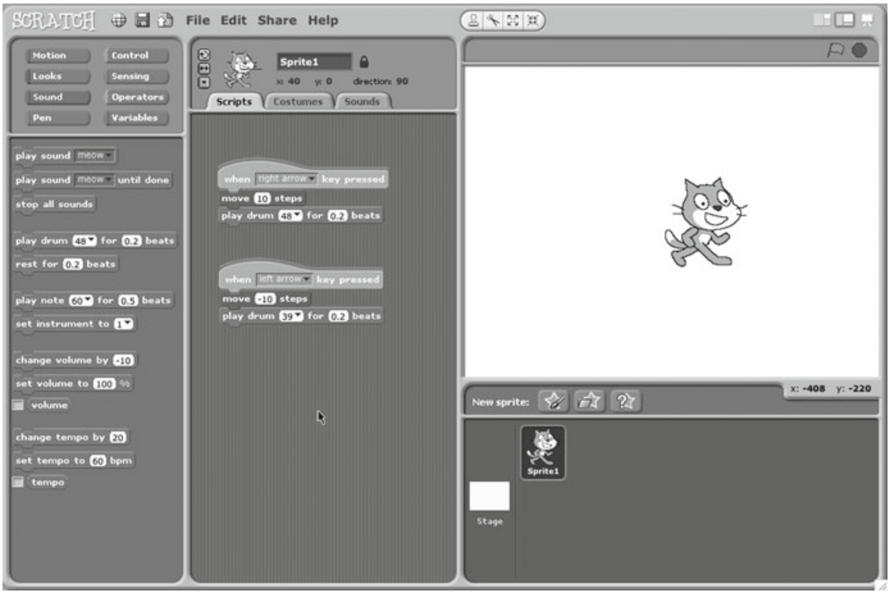


```
when right arrow key pressed
move 10 steps
play drum 48 for 0.2 beats

when left arrow key pressed
move -10 steps
play drum 39 for 0.2 beats
```

Fig. 17.1 Using the Scratch environment to program a cat sprite

Scratch uses a graphical, blocks-based language for programming instructions. Just as you can use LEGO bricks to build up a more complicated structure in the physical world, you can use Scratch programming blocks to build up a more complicated structure in the digital world—in this case, using programming blocks to control the behavior of media elements and objects, called *sprites*, within a Scratch project.

There are more than 100 programming blocks sorted into eight different categories: *motion* (blocks to control the position and direction of a sprite), *looks* (blocks to change the visual appearance of a sprite), *sound* (blocks to play audio clips and musical notes), *pen* (blocks to programmatically draw), *control* (blocks to make decisions or modify the flow of the program), *sensing* (blocks to get information about the state of sprites in a project), *operators* (blocks to perform arithmetic, logic, and string operations), and *variables* (blocks to store data). Blocks from all different categories can be snapped together to program different behaviors.

For example, the *when right arrow key pressed* block (*control* category), the *move 10 steps* block (*motion* category), and the *play drum* block (*sound* category) can be snapped together in a stack, which can be used to control the actions of a sprite (which, by default, is a cat). In this program, whenever the right arrow key on the computer keyboard is pressed, the sprite is moved 10 units to the right, and a tambourine noise is played. Another stack of blocks can be added to move the cat 10 units to the left and then play a handclap noise whenever the *left* arrow key is pressed (Fig. 17.1).

What specific media elements are being programmed (e.g., the cat and drum sounds in the program described above) are as important as *how* they are being programmed, and Scratch was designed to make it as easy as possible for creators to personalize their Scratch projects. Although the cat is the default sprite, it is easy to remove, edit, or add different sprites. Scratch comes with a large media library of sprites, backgrounds, and sounds. Creators can use Scratch's built-in paint editor to create their own visual elements. They can also import audio/visual elements into their Scratch projects by using external tools (e.g., Photoshop or GarageBand) to create elements or by using a web browser to find elements online (e.g., photographs on Flickr).

From this simple process of snapping blocks together and customizing media elements, we have seen a wide variety of projects created. Young people have been using Scratch to create interactive stories and animations based on their favorite pop culture icons or imagined characters, simulations based on math and science concepts, and games that are recreations of classics (like Pac-Man and Super Mario Brothers) or inventions of their own. There is no *one* way that Scratch is being used and we have been continually surprised by how young people have stretched what we thought was possible to create with Scratch.

Background

Constructionism and Software Design

Scratch follows in the constructionist tradition—an approach to learning that emphasizes the importance of constructing, building, making, and designing as ways of knowing; "that knowledge is not simply transmitted from teacher to student, but actively constructed by the mind of the learner. Children don't get ideas; they make ideas" (Kafai & Resnick, 1996, p. 1). Constructionism is grounded in the belief that the most effective learning experiences grow out of the active construction of all types of things, including the construction of computer programs. The Logo programming environment (developed by Seymour Papert and a team of researchers at MIT in the 1960s) was a major part of the constructionist tradition and has been a significant influence in Scratch's development. Logo researchers studied how software design was a meaningful context for young people's learning, particularly the ways in which the creation of computer games supported young people in developing design thinking and understanding mathematical concepts, such as fractions (Harel & Papert, 1990; Kafai, 1995).

More recent research has also supported both playing with and developing software as meaningful contexts for learning. Ito (2009) described the opportunities of children's software for learning as three genres or cultural moments of software: *academic* software, *entertainment* software, and *construction* software. Unlike the academic and entertainment offerings, which organize learning around extrinsic rewards or amusement, Ito posited that the construction genre, which makes central the agency of young people as designers of their software experiences, offers the greatest potential for learning and participation. Salen (2007), whose work has focused on the development of games, described the broad set of capacities that are required for game design—including critical thinking, complex problem solving, and persuasive expression—and the relevance of these capacities beyond a games context, forming the basis of a modern literacy that should be developed by all young people.

The design of software offers young people opportunities to engage in authentic challenges. Generalizing beyond software design, project- and problem-based approaches to learning recognize that the design of solutions to authentic problems contributes to deep and meaningful learning, going beyond the acquisition of superficial facts (Barron et al., 1998; Kolodner et al., 2003; Krajcik & Blumenfeld, 2006). Despite differences in *what* is being designed, all of the design-oriented approaches have a shared belief about the nature of knowledge—"knowledge as constructed by human inquiry rather than knowledge as 'just there'" (Perkins, 1986, p. 19).

Iterative Design Process

This shared belief leads to a consideration of the *process* of design, which can be framed as an iterative approach that involves design cycles of *imagining*, *creating*, *playing*, *sharing*, and *reflecting* (Resnick, 2007). The *imagining* stage involves defining a problem space or imagining possibilities for an experience. A young person asks: What might I want to design? Why might I want to design it? The *creating* stage involves assembling the creative tools and starting to put the design together. A young person asks: What do I need to create my design? What are the pieces that make up my design? The *playing* stage involves testing out the artifact that is being created. A young person asks: Does my creation work? How is my creation aligned with what I imagined? The *sharing* stage involves presenting the designed artifact to others. A young person asks: Who can serve as an audience for my creation? What comments and feedback might I receive from others? The *reflecting* stage involves stepping back from the active design process to think critically about one's progress. A young person asks: What have I figured out with my design? What remains to be understood and developed? These questions lead to new approaches and further iterations of the design cycle. Although described neatly here, the design process is often quite messy, with these stages sometimes happening concurrently, in a different sequence, or with uneven emphasis.

We illustrate this iterative design process with an example. Alex, a 9-year-old, was constantly sharing with his mother the ways in which he could *imagine* modifying and improving the games he enjoyed playing online. His mother introduced him to Scratch and he was excited about the possibility of making his own games. After tinkering with the basics of Scratch for a while, he started to *create* an elaborate maze game. Each level of the game involved navigating a protagonist through a complex maze structure with rewards to collect and punishments to avoid.

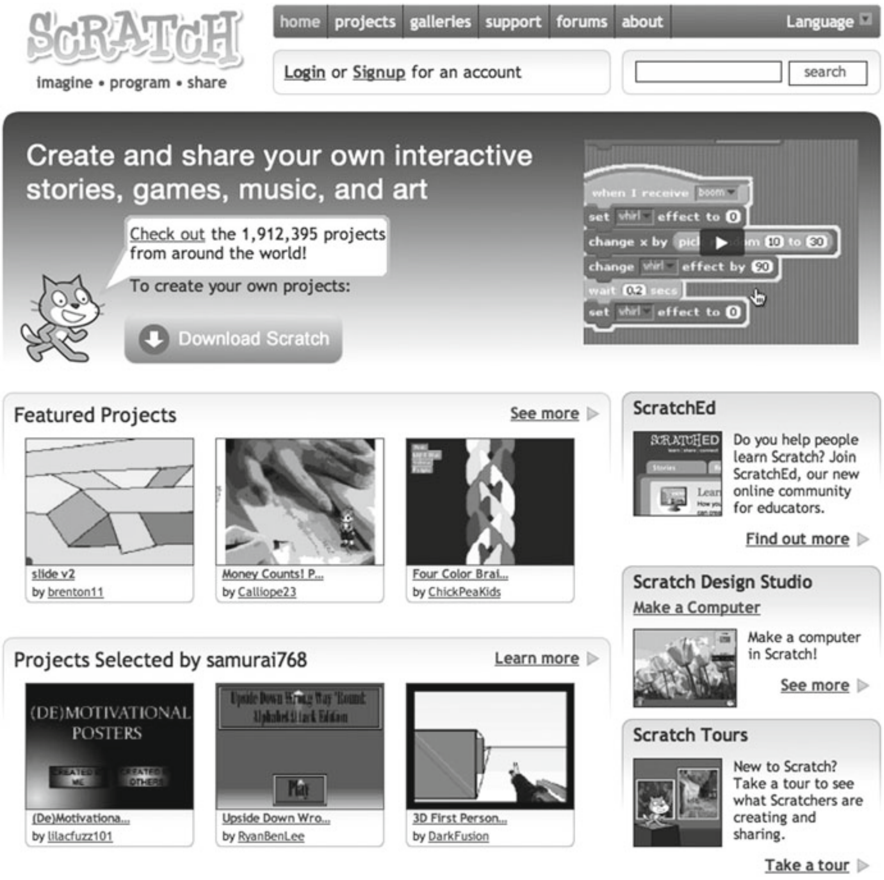
He particularly enjoyed recording his voice and programming the game to congratulate the player whenever a maze level was completed. He continually *played* during his development process—writing a bit of the program, testing it out, writing a bit more, having new inspiration, getting stuck, experimenting—alternating between testing and creating. After a few weeks, he felt that his game was ready to *share* with others. He invited his parents to the computer in the family room and had them try out his game. Both of his parents were suitably impressed by his creation, but his mother suggested that Alex could add instructions at the beginning of the game. Alex *reflected* on her suggestion. It made sense to him because, as a player, he had always read game instructions, but he was not sure how the instructions should be presented. After his parents left, Alex sat down with some paper and a pencil and sketched out what he *imagined* for the next set of refinements to his project.

Exemplars

In the example provided above, Alex worked primarily on his own. However, we know that learning and creativity are enhanced through interaction with others since they are social processes (Csikszentmihalyi, 1997; Sawyer, 2006a). Theories about communities of practice and situated learning give us ways of thinking about how community settings can support a designer's learning by providing the learner access to other designers and designed artifacts (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991; Rogoff, 1994). Based on these theories and inspired by Papert's (1980) model of the samba school, our research group created an accompanying website for Scratch, *the Scratch online community*, where people of all ages come together to share their design work and support each other's learning.

The Scratch online community, launched in May 2007, has become very active, with more than a million registered members sharing, discussing, and remixing one another's Scratch projects (Resnick et al., 2009). Each day, members (mostly ages 8–16) upload more than 2,500 new Scratch projects to the website—on average, two new projects every minute—with more than 2.7 million projects available. The collection of projects uploaded is incredibly diverse and includes interactive newsletters, science simulations, virtual tours, animated dance contests, interactive tutorials, and many others, all programmed with the Scratch environment and its graphical programming blocks (Fig. 17.2).

In addition to enabling people to upload their projects, the site was designed with features typical of community-based content-creation sites, such as Flickr and YouTube. Members can leave comments on projects, annotate projects with tags, indicate admiration of projects by clicking the *Love It* link, and bookmark projects in a list of favorites. Members can also download each other's projects to learn how they were made and then build on each other's work by remixing projects. Members can mark other members as friends, create galleries or collections of projects with others, and participate in discussion forums. Each member has a profile page that



Login or Signup for an account

Create and share your own interactive stories, games, music, and art

Check out the 1,912,395 projects from around the world!

To create your own projects:

Featured Projects

slide v2 by brenton11

Money Counts! P... by Calliope23

Four Color Brai... by ChickPeaKids

Projects Selected by samurai768

(De)Motivationa... by lilacfuzz101

Upside Down Wro... by RyanBenLee

3D First Person... by DarkFusion

ScratchEd

Do you help people learn Scratch? Join ScratchEd, our new online community for educators.

Scratch Design Studio

Make a Computer

Make a computer in Scratch!

Scratch Tours

New to Scratch? Take a tour to see what Scratchers are creating and sharing.

Fig. 17.2 The Scratch online community where young people share their interactive media creations

displays their alias and country, as well as his/her contributions and interactions, such as lists of projects, favorites, friends, and galleries.

Recent research has described the ways in which the social nature of young people's online participation serves as essential motivation and support for developing fluency of participation (Buckingham & Willett, 2006; Ito et al., 2009; Jenkins, Purushotma, Weigel, Clinton, & Robison, 2006). Whether hanging out with friends, playing games, or remixing media, having access to others makes for better participation, as young people are able to support each other in understanding practices and norms. Bruckman's (1998, 2006) work described the cognitive, social, and psychological benefits that an online community provided for individual learners in constructionist activities. From technical support to emotional support, having access to others bolstered individuals' capacities for creative work.

We have seen that the Scratch online community supports young people's development as designers of interactive media. Having access to others supports *all* aspects of the iterative design process (*imagining*, *creating*, *playing*, *sharing*, and *reflecting*), not just the *sharing* stage of design. In the subsequent sections, we will share case studies from the Scratch online community to illustrate the ways in which having access to the community has supported young people's processes of *imagining*, *creating*, *playing*, *sharing*, and *reflecting*. These case studies are based on several years of Scratch online community observational field notes, as well as interviews with young Scratchers.

Exemplars of Imagining

For people who are new to a design tool like Scratch, the *imagining* stage is not just about defining a problem to solve or dreaming up an experience; it is about getting a sense of what might be possible to create with the tool. To help frame the possibilities, the Scratch application comes with a sample projects library. The online community significantly extends this library, with several million projects available online to serve as inspiration for people in the initial stages of a design.

Ten Levels

Courtney, 11, was introduced to Scratch by a friend from school. She was not sure what she might want to create, so she explored the Scratch online community to see what types of things other kids had been creating. She saw lots of different projects that she thought were interesting, but she found one that was particularly inspiring. The project was a game—a series of 100 mazes that increased in difficulty after each level. She thought that it was a great concept and wanted to make her own version of the game, but decided that she would start with fewer levels, perhaps 10 instead of 100. She gathered some paper and a pencil and started to sketch ideas for the mazes in her game. She imagined challenging obstacles to avoid, from spikes to lasers to lava pits, and tricky puzzles to solve. Courtney showed her sketches to her parents and her brother to get feedback for her maze levels, and looked for other maze projects on the website to get ideas.

The online community is not just a repository for projects that inspire the imagination. Rather, it is a location for people to explore shared interests in topics and to create interactive media together. These creative passions serve as another form of inspiration.

Mathematicians

Rebecca is 16 years old and loves mathematics. Rebecca found Scratch after her father suggested that, given Rebecca's interest in mathematical proofs, she might find the logical structures of programming appealing. When she first visited the Scratch website, she started by looking at the projects highlighted on the front page. She enjoyed looking at the list of most-recent projects, but was quickly overwhelmed by the number of projects that she found. Then she discovered the lists of most-viewed and most-loved projects. There were many games and animations, but Rebecca was not finding projects that she thought were personally interesting. She used the Scratch search engine to look for "math" projects and found hundreds of relevant projects in the search results. After interacting with a few dozen projects, which covered a wide range of mathematical concepts, she started to notice that particular member names were coming up again and again as the creators of and commenters on these math-focused projects. She had found a sub-community of mathematicians within the larger Scratch online community. Inspired by this group of people who share her passion for math, Rebecca created numerous projects about the different math concepts that she was learning in school and shared her projects with the online community. Rebecca thinks that the act of creating projects helps her to better understand the concepts that she is learning in school, and she hopes that her love of math will inspire others.

Exemplars of Creating

The large library of Scratch projects available online is meant to be not only a source of inspiration, but a source of building materials to help with *creating* Scratch projects. Not sure how to keep score in a game or how to make two sprites interact with each other? Find a project that does what you are hoping to achieve and examine its Scratch blocks. Every project on the site can be downloaded and its code studied as a way of learning particular techniques. New projects can be created by building up existing projects, becoming *remixes*. Remixed projects—created by young people finding projects, downloading them, changing them, and sharing them on the site—now constitute more than 15 % of all projects on the Scratch website.

Sidescroller Madness

Sean, 16 years old, loves playing video games, particularly sidescroller games. He tried to teach himself programming, but found that it was too complicated to make games on his own. After reading a news article about the launch of the Scratch online community, Sean was hopeful that Scratch might be a better tool for game design. He downloaded Scratch and looked at the sample projects. The sample games were simpler than he had hoped, and there were no examples of the sidescroller games that he was trying to create. He turned to the online community, which at the time had only a few hundred projects, and still was unable to find an example of a sidescroller project. He decided to experiment on his own and discovered that it was easier to create a sidescroller game with Scratch than with other programming languages. When he created a basic game and posted it to the site, other community members responded enthusiastically to the emergence of this genre. Sean continued to make games, each one extending and refining his sidescroller techniques. Remembering his own initial excitement about creating a sidescroller game with Scratch, he decided to make a tutorial project for others. The project, explicitly intended for others to download and remix as the basis of their own sidescroller games, explained the mechanisms of a sidescroller game, step by step.

Studying the code of downloaded projects and developing an understanding of how projects work are powerful opportunities for learning. But whether someone has been using Scratch for 3 days or for 3 years, there will always be challenges that are just beyond understanding, even with access to others' programming blocks. Fortunately, each project on the website includes a link to the person who created the project, and the creators are often available for support and guidance. Sean, for example, made himself available as a consultant to others who needed support beyond his tutorial project. Community members have taken this peer support further, recognizing that when members work together as a *team*, ambitious projects can be created through their collaborative efforts and that the Scratch online community can be used to find others with similar design interests and goals.

Adventure in the Spooky Mansion

Sarah, a 13-year-old, and her 10-year-old brother love Halloween. Months before October 31st, they started planning their costumes and their route to visit neighborhood homes for treats. They both like creating Scratch projects and decided to create a spooky project to celebrate the day. Sarah loves the programming part and her brother loves to draw, but they wanted some help with both and with thinking of a concept for the project. They posted an announcement about their plan on the Scratch forums and invited others to participate in the creation of a project. Another Scratcher suggested creating an interactive project that would have the player navigating a spooky old mansion. Sarah and her brother loved the idea and the three of them started working on the plot of the story. They created an initial draft of the story and posted a link to the project in the forum thread. Other Scratchers were excited about the project and volunteered to help out—some were interested in working on the plot, others the programming, others the art. People working on the project downloaded the latest version, worked on it for a bit, and reposted it to the site, iteratively building up the project. On the day before Halloween, the group of contributors (which at its peak involved more than 20 community members) announced a final version. Community members gave the creators ample positive feedback on their project—a project that would have been challenging for any one of them to create on their own.

Exemplars of Playing

No design works as expected at first, and *playing* is important throughout the design process. Testing and experimenting with one's creations helps a designer understand what is (or is not) working, from trying out an individual block to experimenting with a stack of connected blocks to playing with a well-developed iteration of the project.

Works in Progress

Roan is 11 years old. He was introduced to Scratch at a lunch-hour school club and found that he loved using Scratch to create elaborate animations. But he never had enough time to perfect his creations during club time or at home, so he continued testing and developing his work across settings. He would start a project at the club and then upload it to the online community. Later, he would download it at home, assess what was not working yet, continue to work on it, and then upload it again. A single project sometimes resulted in dozens of uploaded iterations of his work. He knew that other people liked to keep their work secret until a final version was perfected, but he did not mind having his works in progress available to others. Although he initially adopted a post-early-and-often policy as a way of continuing his creative work between school and home, Roan found that he liked using it as a visual reminder of the decisions he made during his development process.

The participation of online community members provides new ways of thinking about the iterative development that emerges from playing with a project. Sometimes individual projects catch the attention of other Scratchers. Instead of one person taking responsibility for testing and refining a particular project, testing becomes an activity that spreads across Scratchers and new perspectives are incorporated in further iterations.

Tetris

Tetris is one of those classic computer games that everyone seems to know. So it was exciting (if somewhat unsurprising) to see a Scratch-based Tetris creation appear in the early days of the Scratch online community. The first version was a simple, elegant implementation of the game. Use the space bar to rotate and the left and right arrows to move the falling black blocks. Get a point for every full line of blocks that is created. Numerous people played the game and made suggestions for how it could be expanded. What if instructions were added to the project for people who do not already know how to play Tetris? What if the blocks were different colors instead of all black? What if you could get a hint about which blocks would be appearing soon? What if you had a score and a count of how many lines were cleared? Over a period of several months, a few hundred implementations of Scratch Tetris appeared on the site, each one the result of a Scratcher having tested and played a previous iteration of the game.

Exemplars of Sharing

In some ways, the *sharing* aspect of the design process is the one to most obviously benefit from the online community. There is a continual sense of activity and audience in the community with more than a million registered members, roughly 300,000 of whom have shared projects on the site. Although sharing creative work with family and friends is a valuable experience, there is a different sort of excitement about connecting with and receiving feedback from people out in the world. In interviews, Scratchers frequently describe the motivation and satisfaction that an appreciative audience offers. However, in addition to more comments from more people, a larger audience can lead to different types of project development.

Response Tester

James is a 10-year-old boy who had been learning about response times in science class—i.e., how quickly a person can respond to an external stimulus and factors that can alter a person's response time. James was curious and wanted to experiment with response times himself. He had seen his older sister use Scratch to create interactive projects that she shared on the Scratch website and he decided to talk with her about his idea for a project that could be used as a response tester experiment. She helped him design a project that measured how quickly the person interacting with the project responded to changes in the project. At the end, the project reported the person's average response time and asked a few demographic questions (age, sex, number of hours of sleep per night). James posted the project to the website and hundreds of Scratchers tried it and shared their response times and demographic answers in comments below the project. He collected the data from the website, and with help from his mother analyzed the results. James wrote a report about the response tester project and shared it with his class at the annual science fair.

Individual projects can attract attention, but there are some Scratchers who have been able to achieve significant cultural resonance with the community by developing a series of popular projects. This situation can result in community-wide visibility for creators, leading to a large fan base for their work and to new forms of creation and participation.

Guest Spot

Caitlin is a 13-year-old girl. She is a devoted fan of anime (Japanese animation) and spends much of her free time sketching her own anime-style drawings. She recently started using her computer as a way of creating sketches. Her best friend learned about Scratch in an introductory computing course and suggested that Caitlin could use Scratch to create animations just like the anime that they both love so much. Caitlin started posting episodes in a story series, which gained a large following in the Scratch online community. Her projects regularly appeared on the front page of the site based on the number of community views, comments, and love-its that they received. Other Scratchers became invested in Caitlin's work, asking when the next episode would be released on the site, making requests for plot and character development, and creating fan projects as tribute to the characters. Caitlin appreciated her growing group of admirers and tried to think of ways to include them in her project development process, while still being able to maintain her vision for the series. She decided to have a "guest spot" in one of the episodes, and invited community members to submit entries for a new character who would appear in that episode.

Exemplars of Reflecting

Stepping back and *reflecting* on one's activities as a creator of interactive media is as important to the process as the other stages of design, and it is in large part what propels us to deeper understanding and learning (Sawyer, 2006b). The community artifacts that surround designers can support reflective activities, as the objects we create can be the objects that help us think about the meaning of our participation.

Scratch Stats

Fitch, a 10-year-old boy, who was relatively new to the Scratch online community, wanted to understand why some people are more popular or receive more attention than others on the Scratch website. On a visit to the website, Fitch found a page that contained visualizations of individual Scratchers' participation. He looked at his own visualization and discovered that the number of comments received was extremely low. For comparison, he decided to look at the visualization of Angela, who Fitch knew had been a Scratcher for several years and had received many more comments. Fitch saw that Angela's number of received comments had gone up and down over time, but what surprised him was that the graph of received comments was the same shape as (but three times larger than) the graph of given comments. Upon further reflection, Fitch realized that the differences in these visualizations were not just coincidence, and he shared his insights with other Scratchers in the Scratch online forums: to get comments, you need to give comments.

Having access to artifacts, such as visualizations and portfolios of projects, can effectively support learners' reflections. However, having access to other people can provide even more specialized scaffolding for learners' reflective practices. For example, others can ask questions about what creators of Scratch projects are (or should be) noticing about their own development as designers.

Puzzle Par

Tom is 13 years old and, for as long as he can remember, has enjoyed puzzles that explore patterns and combinations. One of his favorite games is Swap It, a logic puzzle where the player swaps adjacent colored tiles until the final colored tile pattern is achieved. He decided to create his own version of Swap It and share it with others in the online community. After Tom posted his project, Eric (a more advanced Scratcher) tried out Tom's project and left a congratulatory comment for Tom about his fun project, although Eric mentioned that the project was "pretty easy." Tom was very happy to get feedback on his game, and it helped him think about what it was like for someone else to experience playing his game. Tom was not sure how he might make the game harder, so he thanked Eric for the critique and asked for suggestions: "What do you think I could change to add a bit more of a challenge?" Eric responded with several detailed suggestions for extending the challenge of the game play, including adding the notion of par for each level, the minimum number of swaps needed to solve the level. Tom was very appreciative of the suggestions and thanked Eric again for his help, indicating that he would keep working on his project and add the par feature in the next version.

Next Steps

These case studies from the first 3 years of the Scratch online community illustrate some of the ways in which an online community supports young people's development of interactive media across the design process. They also provoke questions about the implications for other learning environments. In all of the design process stages, there is interplay between community *artifacts* and community *members*. For *imagining*, both people and projects serve as sources of inspiration, highlighting what might be possible to design and ways of being a designer. Future research might explore, *how imagination is ignited* (*or limited*) *by examples that we make available to young people.* For *creating*, the online community offers a library of projects to learn from and remix. There are also people who can serve as guides and collaborators, enabling a Scratcher to be involved in the design of artifacts that they would not have been able to develop on their own. Future research for this design process might explore, *how we can rethink what it means to create, moving away from individual-centric and instruction-centric approaches to learning.* For *playing*, the online community enables multiple Scratchers to be involved in testing and experimenting with iterations of a project or for an individual Scratcher to engage in multiple iterations across contexts. In this area, future research might investigate, *how we can increasingly focus on the processes of design and learning, rather than the products.* For *sharing*, having such a large and appreciative audience for their projects (and sometimes for themselves as designers) is highly motivating to many Scratchers, even if a community the size of Scratch seems unimaginably large to most community members. For the process of sharing, we might ask, *how we can find ways of connecting young people to authentic and peer audiences.* Finally, for *reflecting*, community documentation supports critical self-examination, which is further supported by the active conversations that take place among Scratchers. In this area, future research might examine *how we can create opportunities for young people to do and to think about the doing.*

With Scratch, hundreds of thousands of young people are creating their own interactive media and participating as designers. Moreover, the online community supports them as they participate in project design. However, while many young people thrive in the self-directed environment of the online community, others find the space difficult to navigate. To facilitate participation, we have developed other forms of scaffolding and support, including tutorials, curated collections of projects to highlight specific computational concepts and practices, and design challenges and activities to encourage new computational explorations.

Although these resources have contributed to supporting young people as designers, work remains in making design experiences available to broader audiences of young people. Many of the early adopters of Scratch have been young people from homes with technology advocates: parents who are computer programmers, siblings who enjoy tinkering with programming tools, and aunts or uncles who are engineers. Regardless of our efforts with Scratch, these young people are certain to have many opportunities for positive technology experiences.

Given that the ability to understand and negotiate technological artifacts is becoming increasingly important in the lives of young people, the ability to design technology is not a luxury that should be reserved for a select few who have access to support at home. As a society, we need *all* young people to be able to solve open-ended problems and to be self-regulating, passionate learners—the very qualities that young people develop while engaging with Scratch and iterative design processes, qualities that we hope young people will develop in school settings.

We see schools as a critical venue for broadening participation in design activities, reaching young people who might not have this support at home, and giving young people additional opportunities to engage in the iterative design processes necessary to fully participate in society. To this end, we have been working with teachers to support their understandings of Scratch, iterative design processes, and ways of including design in teaching practices across age ranges, from elementary to college, and across the curriculum, from art to science to languages to social studies.

Our approach to supporting teachers mirrors our support of young Scratchers. Just as we see young people as designers, we see teachers as designers—not of interactive media, primarily, but of learning environments. As designers, teachers can similarly benefit from an online community in which their processes of designing—the *imagining*, *creating*, *playing*, *sharing*, and *reflecting* of learning environments—are enhanced through interactions with artifacts and others. To this end, we developed a companion community to the main Scratch online community called ScratchEd (http://scratched.media.mit.edu) where Scratch educators can read and share stories, exchange and provide feedback on resources, ask and answer questions, and find each other based on geography or interests. Launched in summer of 2009, the Scratch educator community has grown to more than 4,600 educators in its first 2 years, and we have already seen benefits to teachers' design processes that parallel the benefits we have documented in young people's design processes.

Design experiences are not predetermined. The path that a designer will follow is uncertain and can lead to unexpected challenges. Whether a young person designing his/her own interactive media with Scratch or an educator designing learning environments, designers of all ages and backgrounds can find support for their learning experiences in contexts where they have access to others. An online community affords opportunities for designers to interact with new artifacts and new people, which provide support across the design cycle. Imagining, creating, playing, sharing, and reflecting are all enhanced through interactions with the community.

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Chapter 18
Epilogue: Designing and Integrating Emerging Technologies for Learning, Collaboration, Reflection, and Creativity

Nancy C. Lavigne and Chrystalla Mouza

We live in an increasingly complex and rapidly changing world where technology is an integral and pervasive part of our everyday lives. Technology can expose us to complexity and open up new worlds for us to explore, offering opportunities for academic, personal, and professional growth. Technology can also be designed and integrated to support us in navigating demanding environments, working with challenging ideas, interacting and collaborating with others, building communities that enable us to develop in various ways, and creating meaningful and innovative products. In essence, the potential of technology for transforming lives depends in part on how designers, teachers, and learners conceive of it as fulfilling their needs and enabling them to meet their goals.

In education, goals geared towards attaining twenty first century skills that allow learners to solve complex and nonroutine problems, think critically, innovate, collaborate, communicate, regulate thoughts and emotions, among others, are increasingly valued (National Research Council [NRC], 2011; Trilling & Fadel, 2009). In the current conceptualization, reflection is vital to many of these skills, particularly critical thinking, innovation, and self-regulation (Trilling & Fadel, 2009). Moreover, the role of technology in facilitating the development of twenty first century skills, including digital literacy skills, is featured prominently (Trilling & Fadel, 2009; U.S. Department of Education [USDOE], Office of Educational Technology, 2010). Thus, current expectations for how students think about and interact with content, problems, learning partners, learning processes, and technology are high. From this perspective, the charge for instructional designers, educators, and researchers is to consider the range of technologies that are available and how they can be integrated into learning experiences so as to optimize learners' motivation to learn, as well as their ability to acquire and develop twenty first century skills.

N.C. Lavigne (✉) • C. Mouza
School of Education, University of Delaware, Willard Hall 219 D, 19716, Newark, USA
e-mail: nlavigne@udel.edu; cmouza@udel.edu

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The volume *Emerging Technologies for the Classroom: A Learning Sciences Perspective* is ripe with examples of how four types of technologies—visualization tools, networked and networking technologies, technologies for anytime anywhere learning, and games—can enhance motivation, facilitate learning, and foster collaboration, creativity, and reflection. By *emerging* we mean technologies that are viewed as having the capacity to significantly affect the processes and outcomes of teaching and learning. These include technologies whose integration has been extensively researched as well those whose potential is now being investigated. Moreover, the types of technologies represented in this volume are identified in the 2010 Horizon Report as those expected to have the greatest influence on college campuses in the next 5 years (Johnson, Levine, Smith, & Stone, 2010). This alignment is important because of increased concern regarding the congruence between K-12 learning experiences, which is the primary focus in this volume, and those received in college or the workplace.

Our purpose in this chapter is to collate information from the volume that will assist instructional designers, teachers, administrators, researchers, and policy makers in making decisions about designing or integrating emerging technologies. We employ the term *integrating* rather than adopting or implementing because successful technology use often requires that it be integrated into curriculum activities in meaningful and purposeful ways (Sawyer, 2006). We begin the chapter by discussing how emerging technologies fit within the larger context of twenty first century skills, and then we highlight six common design or integration issues that were raised in the volume. We conclude by identifying the next steps that must be taken to fully benefit from emerging technologies.

Twenty First Century Skills

As educators, our practice is driven by the goals we expect our learners to attain. These goals are developed in local contexts, but they also must be congruent with state or Common Core State standards (National Governors Association, Council of Chief State School Officers, 2010). In designing or integrating technologies into the curriculum, we are similarly concerned with ensuring such alignment, an issue that is explicitly addressed in several chapters of this volume (e.g., Chaps. 2, 4, 7, 8, 11, and 15). Moreover, many scholars, postsecondary educators, and business leaders, have expressed concern with the knowledge, skills, and practices students currently learn in school because these are deemed insufficient to meet current and future demands of college and the workplace (Alliance for Excellent Education, 2008; Chait & Venezia, 2009; NRC, 2011). Those most affected by this incongruity are low-income and ethnic minority students (Chait & Venezia, 2009).

The kinds of skills students need to be ready for college and work are often referred to as *twenty first century skills* (NRC, 2011; Trilling & Fadel, 2009). NRC (2011) classifies these skills into three categories: (a) *cognitive*—nonroutine problem solving involving creativity, systems thinking, and critical thinking (also requires reflection); (b) *interpersonal*—sensitivity and ability to address diversity, ability to work and develop relationships with others on a team, and ability to communicate and interact with others effectively; and (c) *intrapersonal*—ability to adapt to individuals, situations, and change itself, to manage time, and to be self-directed (involves reflection). These skills parallel those described by the Partnership for twenty first Century Skills (Trilling & Fadel, 2009; see also P21 framework at http://www.p21.org/overview).

It would be wise to keep such skills in mind. Although the Common Core State standards for mathematics and English language arts (ELA) do require thinking at a higher level than emphasized in previous standards for most states (Cobb & Jackson, 2011; Porter, McMaken, Hwang, & Yang, 2011) and are consistent with many twenty first century skills (e.g., critical thinking), they do not explicitly draw attention to other skills that are valued beyond K-12 (e.g., teamwork in mathematics and self-regulation in ELA).

According to Trilling and Fadel (2009), four mutually reinforcing factors have propelled us towards twenty first century skills: (a) the requirements of today's workplace to innovate, solve problems, and collaborate with others; (b) technology and digital devices that serve as tools for enhancing individuals' ability to think, communicate, collaborate, learn, create, etc.; (c) digital lifestyles that result in youth having a new set of expectations for learning, which include autonomy to select, modify, and personalize learning tools according to their needs, ability to express themselves in ways that are consistent with their identities, opportunity to develop relationships through collaboration, and possibility to innovate, among others; and (d) the knowledge gained from research on how individuals learn and are motivated, which is consistent with college and workplace demands as well as the expectations expressed by today's youth.

Our volume reflects the confluence of these factors. For instance, the work described in all of the chapters is based on principles or frameworks that are grounded in learning or motivational theories as well as empirical research (factor d). In addition, many of the emerging technologies elicit twenty first century skills (factor a) to varying degrees (e.g., STOCHASMOS, described in Chap. 8, was designed specifically to foster reflection), although the focus is not always on how to design for such skills (e.g., Scientopolis and SURGE, described in Chap. 15, were designed to promote intrinsic motivation but they also engage students in nonroutine problem solving). Finally, emerging technologies that elicit twenty first century skills in both classrooms and in children's lives are featured (factors b and c). Most chapters describe how technologies can be designed or integrated to foster motivation, learning, collaboration, creativity, and/or reflection (i.e., 2–8, 10–11, 14–15). Other chapters describe how these outcomes arise when youth use digital technology as part of their lifestyle either informally to pursue personal interests (i.e., 16–17) or in conjunction with formal learning tasks (i.e., 9, 12, 13). Several chapters reveal the opportunities that emerging technologies provide in assisting with children's developmental needs such as autonomy, relationships, and identity, which is shown in other research (e.g., Bruckman, 2000).

In the next section, we focus on design and integration issues that were common across many chapters, specifying when applicable how these might inform pedagogical practices for promoting twenty first century skills.

Design and Integration Issues

Determining which technologies to integrate into classrooms requires consideration of many factors. A basic issue is infrastructure. For example, Web 2.0 tools and mobile devices would not be an option unless schools have access to wireless networks. Connectivity at home is also a factor, particularly when the goal is to expand learning opportunities or when a child is homeschooled or attends a virtual school. A related issue is whether technology exists to meet intended goals. For example, White (Chap. 6) explains that connectivity between handheld devices for the purpose of sharing graphical data among various small groups of students is typically not a built-in capability. Instead, technologies that allow communication between small groups and the teacher who receives small-group data and controls the classroom display are more common. In White's case, researcher ingenuity resulted in making this connectivity available through other means. Thus, products that scholars create and empirically test should be considered in addition to commercially available ones, and designers should conduct needs analyses in schools so that desired features are integrated into technologies.

Further, the cost and availability of hardware for every student is an issue. Sometimes educators have to be creative in generating solutions. In the case of digital fabrication, Chiu, Bull, Berry III, and Kjellstrom grouped students with different design roles together and added constraints on the size and complexity of the design to avoid long line-ups at the printer (Chap. 4, Exemplar 2: Elementary Classrooms With the University of Virginia). These modifications were simple yet they are also consistent with learning principles, such as providing opportunities for collaboration with peers.

The aforementioned issues pertain to technical aspects that influence decisions about technology integration. However, a critical set of issues deals with pedagogical aspects. Six design themes emerged from chapters in this volume relating to pedagogy: (a) grounded design and integration; (b) diversity; (c) engagement; (d) learning across contexts; (e) structure and support; and (f) impact on pedagogical practices. We discuss each next.

Grounded Design and Integration

Technology used for pedagogical purposes must be designed and integrated according to principles derived from theoretical and empirical work. For instance, Cavanaugh and Liu state that a key component of learning in virtual schools is the interaction that students have with content, teachers, and peers (Chap. 11, Background). Simply putting courses online without this critical design element is problematic, particularly in light of theory suggesting that adolescents have a developmental need for a sense of belonging and relatedness and evidence suggesting that relationships helps keep teens in traditional schools (Juvonen, 2007). This need is unlikely to change when students leave these classrooms and opt for virtual schools.

Integrating technology into the curriculum in a systematic manner is equally important. Gerard et al. (Chap. 5) point to earlier work showing that stand-alone science visualization tools were less effective than when they were integrated into a learning environment in which support was embedded for engaging students in visualization activities. Roschelle, Courey, Patton, and Murray (Chap. 3) make a similar case with respect to videos posted on sites, such as YouTube, which they refer to as just-in-time resources. These videos illustrate how to solve mathematics problems but they are not tied to activities that guide learners in thinking about why a procedure works and how the underlying concepts relate to other mathematical ideas. Students' reliance on such resources can result in disconnected knowledge and a lack of principled understanding. The authors argue that incorporating videos in Dynabooks designed to link and build on mathematics ideas in multiple, dynamic, and systematic ways has stronger potential than stand-alone videos. Altogether, these examples illustrate the value of grounding technology development in research and integrating technology in a meaningful way.

Each chapter in this volume outlines a framework or a set of guiding principles for designing or integrating an emerging technology. The designs are not necessarily at the same grain size, due in part to the theoretical perspectives upon which they are based. Many of the emerging technologies embody principles from situated learning and socio-cultural theories (e.g., collaboration and authenticity). Other designs focus more on cognition than practices or communities (e.g., strategies for comprehending text (Chap. 3), integration of new knowledge with existing knowledge (Chap. 5), and attention to and ability to process relevant information (Chap. 14)). These latter designs are at a smaller grain size than those generated based on situated learning theory. However, a design principle, such as offering opportunities for collaboration, can allow for meeting goals for learning that are at both finer (i.e., conceptual change) and larger (i.e., social skills) grain sizes. Thus, a range of theoretical views provides an opportunity to target learning at different grain sizes depending on the nature of our goals.

Finally, Vahey, Knudsen, Rafanan, and Lara-Meloy (Chap. 2) remind us that anchoring the design and integration of emerging technologies in theory and research is insufficient; we must also broaden our lens and keep the larger system in mind. They describe a *curricular activity system* in which design or integration decisions are based on existing relationships amongst teachers, students, and content. Designing at this grain size adds a layer of complexity as it means achieving a balance between the goals of instructional designers and curriculum developers and those inherent in relationships that are already part of the system. Such reflection will entail modifying the curriculum, materials, and existing pedagogical practices employed for teaching, assessing, and managing the classroom in certain ways.

Diversity

It is clear that modifications will be needed to address the needs of a wide range of learners. Roschelle et al. (Chap. 3, Diversity) provide compelling statistics showing that classrooms are becoming increasingly heterogeneous in terms of language, ethnicity, income levels, and ability (i.e., learning disability and gifted). It is therefore imperative that diversity be at the forefront in designing and integrating emerging technologies. Four chapters in this volume explicitly address this issue. Vahey et al. (Chap. 2, Exemplar 1: SimCalc) provide evidence that disadvantaged learners (i.e., low-income and English Language Learners) engage with and understand mathematics deeply when technologies enable them to manipulate and dynamically represent information in multiple ways (e.g., various displays, such as tables and graphs, and different forms of communication, such as verbal explanation and written narratives). This finding has been replicated in several studies.

This research base underlies the Universal Design for Learning (UDL) framework proposed for designing Dynabooks and provides guidelines for building in supports for diverse learners within digital texts (Chap. 3, UDL as a Framework). The three overarching UDL principles are to represent information in various ways (e.g., presenting information through multiple modalities), offer alternative ways of acting on content and expressing understanding (e.g., provide different ways of interacting with content depending on physical needs), and engage students in different ways (e.g., provide options that enable students to choose their learning tools). Although these principles are described in relation to digital texts, they can be applied to other emerging technologies. For instance, Mouza and Cavalier (Chap. 10, Laptops and Technological Literacy) describe how use of a laptop enabled a student with cerebral palsy to overcome limitations associated with paper-and-pencil materials (i.e., principle of providing a way of acting on content that overcomes physical difficulties).

Similarly, Web 2.0 technologies described in Part II of the volume (e.g., wikis, discussion forums in management systems, chats, social networking media, etc.) offer options for communicating ideas within an emerging technology. As Greenhow and Li point out, one feature of a social networking technology, *Remix World* (RW), which middle and high school students reported as enhancing their ability to create and share media products, was that feedback could be provided through multiple modalities (Chap. 9, Exemplar 1: Collaboration With a Social Networking Application). In fact, many chapters in this volume describe features of emerging technologies that illustrate some UDL principles.

In some cases, certain emerging technologies may be supplemented with offline experiences to accommodate student differences. For instance, Cavanaugh and Liu's preliminary findings suggest that combining online and offline communication might be fruitful in virtual schools geared towards middle school learners, which increasingly serve students with disabilities (Chap. 11, Demographic Factors Influencing Success in the Program's Online Courses). They recommend that online instructors engage their full-time students in academic activities outside the virtual school so that learners can interact with others offline to enhance online learning (e.g., through field trips or participation in a book club). Students enrolled in virtual schools on a part-time basis usually also attend traditional schools, and their goal is to receive remediated or accelerated instruction virtually. Consequently, they can benefit from the face-to-face interaction that occurs in a classroom, which is missing from full-time participation in virtual schools. Cavanaugh and Liu conclude that a blended program where supports are embedded online as well as provided in the community may be needed to adapt to learners who have specific needs.

The main point is that emerging technologies expand the range of options available to educators for addressing diverse student needs. These options can be built into an emerging technology or they can be provided in conjunction with other technologies (e.g., networking technologies along with visualization tools) or with offline experiences. Any of these possibilities requires careful attention to the body of research showing positive impacts on students who are currently underserved in education (e.g., providing multiple means for representing and communicating information).

Engagement

A pervasive goal in education is to engage students in learning so that they are attentive and mindful. Engagement involves three dimensions (Fredricks, Blumenfeld, & Paris, 2004): (a) behavior (e.g., participation in activities such as number of times students interact with virtual world characters, embedded tools, objects), (b) cognitive-motivational (e.g., putting forth effort, belief of competence in content area or self-efficacy, desire to be optimally challenged), and (c) emotions (e.g., interest, curiosity, sense of belonging, and affect).

Authors in this volume sought to foster various aspects of student engagement through open-ended activities that required problem solving, inquiry, and design. Altogether, the preliminary findings from the chapters suggest the following: (a) converting a digital design into a tangible product and being challenged conceptually through the use of fabrication technologies can foster student interest as well as engender a positive attitude towards mathematics and a confidence in being able to solve mathematics problems; (b) enabling students to explore interests and personalize their learning in some way can engage them in learning through virtual worlds, games, and mobile technologies, and possibly motivate them to persist in virtual world activities; (c) allowing students to explore real-world issues and content can engage them in learning through mobile devices and laptops; and (d) developing a public identity through social networking media in which students interact with others who are visibly engaged in civic activities (as reflected in published comments, votes, friend invitations, and completion of civics challenges) can foster civic engagement.

An additional goal is for students' engagement to translate into learning. Preliminary research suggests that fabrication technology can foster learning gains as well as interest and self-efficacy. In addition, a narrative-centered learning environment (i.e., CRYSTAL ISLAND), described by Lester, Rowe, and Mott, resulted in both learning gains and engagement (Chap. 15, Impact on Motivation and Learning). CRYSTAL ISLAND immerses students in an environment that contains interactive stories (i.e., the narrative) for solving mysteries requiring science content taught in middle school. It is designed based on four factors involved in intrinsic motivation: challenge, curiosity, control, and fantasy. This work is promising because it suggests that game-based learning environments are not one-dimensional and thus have educational value when carefully designed. Moreover, three of these factors (i.e., curiosity, control, and challenge) may play a role in motivating students to learn mathematics when they use visualizations and are asked to communicate and evaluate interpretations through narratives (Chap. 2, Benefits of Dynamic Representational Systems in Mathematics Education). Thus, features common to these two emerging technologies that have potential for fostering learning and engagement seem to be narration, interaction with objects, and rich learning activities.

Three recommendations for fostering engagement are provided based on this work. First, narrative elements can be effective but they should be selected carefully so that they elicit a sufficient amount of curiosity without distracting students. Lester et al. specify that a narrative should enable students to feel immersed in an environment without drawing their attention away from the actual learning goals. Second, Greenhow and Li suggest that instructors tie students' interests and current events (e.g., debates surrounding social unrest) related to learning goals (for civic education), which would enhance the relevance of the curriculum. Finally, Squire suggests that teachers create *memorable moments* as a way to engage learners by strategically presenting the unexpected, a common practice in game design that sustains students' attention through the element of surprise or intrigue (Chap. 13, Exemplar 1: Saving Lake Wingra—The World as a Gameboard Through Layers of Data). This tactic is similar to the intervention Fields and Kafai created where they asked adolescents to change the look of their avatar and experience the reactions of Whyvillians as a way to challenge the values and norms that are part of this virtual world (Chap. 16, Exemplar 1: Promoting Avatar Design Through A Costume Contest).

Connecting Learning Across Contexts

Educators are primarily concerned with school-related learning, which is formal in nature, and thus gravitate towards technologies for learning (Halverson & Smith, 2010). However, quite a bit of learning occurs beyond the confines of schooling, and digital technologies where learners drive the learning (i.e., technologies for learners) play an integral role in that process (Halverson & Smith, 2010). Chapters in this volume describing technologies for learners demonstrate the various ways in which such environments are beneficial to children and adolescents, and collectively, affirm the idea that such technologies may have value for enhancing other facets of education (Thomas & Brown, 2011). These chapters offer different options for bridging the gap between formal and informal learning.

One way to connect learning across settings is to design learning opportunities such that the knowledge and skills learned in one context are applied in other contexts. For instance, networking technologies that connect handheld devices enable learners to use the digital skills they acquire in informal settings to formal tasks without teachers having to worry about Internet safety (e.g., Chap. 6). Similarly, opportunities can be provided for students to extend the knowledge and skills acquired formally to an informal setting. For instance, laptop use supported a student's ability to engage in a project of personal value (e.g., research, plan, carry out, and promote a fund-raising and awareness campaign for United Cerebral Palsy) for a course (e.g., business), which he was then able to share with members of an international association in a multimedia presentation as part of a state competition (see Chap. 10, Laptops and Student Learning). The advantage of designing instruction so that students can extend learning across contexts is that it can enhance the relevance of school learning tasks (Shuler, 2009).

Perhaps the most promising for making barriers between informal and formal learning porous is mobile technology. Squire (Chap. 13) uses the notion of *multiplicity of place* to illustrate this intersection. The goal here is for the two worlds to overlap substantially. The GeoHistorian project is an example of how this objective can be accomplished. In this project, elementary school-aged children created digital stories about historical sites in their area, which they made available on the Internet (Chap. 12, Exemplar 3: The GeoHistorian Project). This accessibility enabled visitors to the historical sites to learn from the digital stories through mobile devices that are used to scan a Quick Response code provided at the site. Thus, the students created a course product that is actually utilized by the general public on an ongoing basis, one that they themselves can view on site or in the classroom.

Other examples require students to collect data in the real world such as observing scientific phenomena, interviewing key city officials, and taking pictures. These data are presented to a mock city council (Chap. 13, Exemplar 1: Saving Lake Wingra—The World as a Gameboard Through Layers of Data) or used to create Augmented Reality games in a semester-long high school course (see Chap. 13, Exemplar 3: Mobile Design Workshop). The value of the students' work for the outside community is reflected by the fact that some of the solutions offered to the mock council regarding the ecological problem were actually implemented. Moreover, the process is made that much more authentic when students navigate between the two environments seamlessly based on their project goals, as was the case in the high school course.

Thus far, overlapping informal and formal contexts through mobile technology appears to be effective in engaging students and fostering achievement, argumentation skills, perspective taking, and learning across content areas (for details see Chap. 12, Exemplars and Chap. 13, Exemplars). Technology integration involved project or design oriented activities requiring interdisciplinary knowledge. These elements are not surprising given that students deal with the complexity of the real world *in* the real world and create solutions or products that are meaningful to them and others in the community. Co-teaching could be a way to facilitate teachers' integration of mobile technologies for interdisciplinary activities, which can be demanding.

This idea of educational partners sharing the teaching responsibilities can be applied to social networking sites, similar to Facebook (i.e., RW and *HotDish* [HD]), designed for educational purposes. The research so far suggests that such sites enhance students' ability to communicate in thoughtful ways and to create and share media, as well as foster strong content knowledge and augment civic and political activities (Chap. 9, Exemplars). These are positive outcomes. However, social networking sites tend to be blocked in schools. Thus, Greenhow and Li (Chap. 9, Advice for Educators) propose creating partnerships such that community members working in afterschool programs, for instance, where students are likely to use social networking media, can help connect and extend students' learning of content (e.g., civics) to personal activities and interests (e.g., involvement in a civic or political group on a social media page). Teachers can draw upon students' experience in the informal setting to introduce or explore concepts in more depth in class. Thus, building a community of educators from multiple settings can help bridge the gap between contexts. Dede (2010) suggests the partnerships in such a *distributed* model be formalized such that informal partners become professional educators through training, licensing, and/or certification.

A variety of skills can also be elicited in digital games that children design and play in their leisure time, including those related to formal schooling, such as science, technology, and mathematics as well as the twenty first century skills of collaboration, reflection, and creativity. How can we capitalize on the benefits of such informal learning? One way is to design a learning environment in which students create games as part of the curriculum (see Chap. 13, Exemplar 3: Mobile Design Workshop). Another option is to integrate virtual worlds containing educational games into classrooms. For instance, Fields and Kafai suggest that students could be asked to create cheat sites for how to solve the games that each person in the class would add to and revise, in effect, producing a knowledge-building community (Chap. 16, Discussion and Next Steps). An additional goal is for students to reflect on the game design as critical consumers and to create designs that reject unproductive and distorted views that are embedded in games. The authors also propose an alternative that does not include digital games: Having students design cheat sheets for doing well in a course that contains information such as guiding questions, examples of concepts, when particular procedures apply, learning strategies, etc.

In summary, social networking sites, digital games, and virtual worlds do result in learning that can be tied to content or skills focused upon in school. A variety of recommendations have been made for doing so, including creating a knowledge-building community with members in a school setting as well as outside of this context.

Structure and Support

An issue that arises in design is the extent to which structure should be provided to support learning. On the one hand, open environments with little structure can provide opportunities for autonomy and creative expression. These features can be appealing to youth who desire making their own decisions and being in control. As Fields and Kafai illustrate, adolescents may even go so far as to circumvent built-in constraints (i.e., rules) of digital games to achieve their own personal goals. For instance, adolescents in Whyville created a form of play that involves flirting where they compete to get the most girlfriends or boyfriends and experiment with different ways of obtaining this kind of relationship (Chap. 16, Exemplar 2: Creative Language Play Through Flirting Performances). Moreover, they bypass language filters in the chat area of the virtual world by using terms (e.g., sessy) that approximate a word not allowed by designers (e.g., sexy) or by adding spaces in between each of the letters in the word. The authors refer to such behavior as *socially transgressive creative play*. This form of play illustrates the creativity that can ensue when youth are driven by their desire for relationships. In this sense, less structure is better because it gives adolescents the freedom to create and express themselves in ways that are not always possible in other settings.

On the other hand, too much openness can be overwhelming to some learners; they can easily lose sight of the goals in such environments, not knowing what information is relevant or how to navigate to find what they need. Under these conditions, guidance is necessary. We discuss three ways in which students can be assisted while engaged in rich learning experiences: (a) embedding supports into an emerging technology, (b) structuring learning experiences for the integration of a technology, and (c) incorporating feedback opportunities.

Embedding Supports

Reducing the complexity and building supports into emerging technologies are ways to maintain learners' focus and engagement in learning. Nelson et al. make virtual worlds with science content more manageable by using multimedia principles to cue students to relevant information (i.e., signaling) and to enhance processing of information based on placement of that information (i.e., continguity). They found that cuing learners visually can reduce students' perception of the intellectual effort required to process information, but only if searching for information is an essential task (Chap. 14, Exemplars). In addition, implementing the signaling principle can enhance the efficiency of students' learning since it involves making relevant information salient thereby guiding problem solving. However, as Vahey et al. point out, efficiency should not come at the expense of clarity (Chap. 2, What are Dynamic Representational Environments?). In other words, we should be careful not to jeopardize deep understanding of content by shortcutting the learning process too quickly.

Other kinds of supports can be incorporated into emerging technologies as part of the design process to assist students in learning and working with complex ideas collaboratively. Built-in supports for enhancing learning, collaboration, creativity, and reflection include the following: (a) multiple "hot spots" in dynamic representations that restrict students' learning to only those ideas that are mathematically viable (Chap. 2, What are Dynamic Representational Environments?); (b) embedded assessments, hints, and guidance for data collection and use of evidence in an inquiry environment that includes visualization tools (Chap. 5, Web-based Inquiry Science Environment [WISE]); (c) templates for guiding data interpretation and evidence-based explanations and tools for promoting the sharing of data and explanations with peers asynchronously and synchronously in a networked learning platform (Chap. 8, Exemplar 1: The STOCHASMOS Web-based Platform to Support Collaboration and Reflection-in-Action); (d) group planning page for managing group work and processes, embedded reflection notes, and a peer review requirement (Chap. 7, Phase 2: Collaborative Knowledge Construction); and (e) tutorials, peer projects, and activities to explore new ideas for games (Chap. 17, Next Steps).

The embedded supports described above have contributed to the positive outcomes found in integrating emerging technologies (see chapters for details). They have also all been researcher-developed. However, it is possible for teachers to add support into some commercially available technologies. For example, wikis are inherently open-ended and were not designed based on a pedagogical model (Chap. 8, Exemplar 2: Wikis in Support of Collaboration and Reflection-on-Action). An easy solution is to add prompts on the wiki pages to guide students. However, Kyza points out that prompts are insufficient. Teacher–student interactions and inter-group collaboration also need to be supported. Similarly, Slotta and Najafi supported graduate university students' collaborative knowledge-building by requiring that groups create a wiki page on a particular knowledge-building media, construct a homework assignment for peers where the latter have to experience using the media the former is researching, and collate the responses (Chap. 7, Exemplar 1: Use of Wikis in Higher Education). Thus, students' learning was structured by engaging in specific activities associated with the wiki.

Structuring Learning Experiences

In essence, the task requirements that Slotta and Najafi describe provide an example of how to structure learning experiences to maximize the benefits of an emerging technology. Thus, configuring learning experiences is an additional way to assist learners on open-ended tasks. A second example involves structuring collaboration so that tasks are distributed to ensure interdependence and individual accountability, which supports collaboration and creativity (Chap. 7, Exemplar 2: A Drupal Community for a High School Climate Change Curriculum). A third example consists of seamlessly transitioning between small group and whole-class discussions for viewing, discussing, and evaluating multiple representations of key disciplinary concepts with the aid of classroom networks (Chap. 6, Exemplars). Careful attention is paid to which ideas are best conveyed in which format (certain formats are open-ended and others constrain students to specific ideas) and the sequence in which these experiences are provided throughout the class period. Moreover, these decisions are made with an eye towards obtaining information about how well students grasp the content as they engage in the tasks. Thus, learning experiences can be structured to make students' thinking visible so that teachers can make pedagogical adjustments on an ongoing basis.

Sometimes an emerging technology can structure learning experiences automatically, and in this way can address potential challenges students have with other types of emerging technologies. For instance, Chiu et al. indicate that students can sometimes overestimate their understanding because complex ideas seem so clear when illustrated through technology. An additional challenge for them can be relating what is learned in a virtual space to objects in the physical space. The authors argue that fabrication technologies offer a solution to both problems. Students are required to create designs using software and then to produce them into prototypes using hardware (Chap. 4, Constructing Understanding Through Engineering Design). Learners obtain feedback on the accuracy of ideas they represented in the virtual space by examining and testing the physical artifacts. Consequently, they are able to see exactly how a tangible product exemplifies design ideas created virtually. Thus, fabrication technologies structure learning activities so that students constantly move between the abstract and the concrete. In this sense, the concrete product supports the virtual design process as well as students' conceptual understanding, creativity, critical thinking, and reflection.

Providing Feedback

Feedback is integral to learning with emerging technologies. In this volume (a) learners obtained feedback on their mathematics and science ideas by observing changes to representations via visualization tools and by producing physical artifacts to visualize their designs; (b) teachers received feedback about the effectiveness of their instruction indirectly by analyzing and reflecting on student responses during in-class activities and on assessments; and (c) students received comments, suggestions, and information about their work or status in a group or community from peers, mentors, and teachers via social networking technologies, networked technologies, games, design-based virtual worlds, and virtual schools.

The findings suggest that feedback was effective in enhancing motivation, learning, collaboration, reflection, and creativity (see Chap. 11, Classroom Activity Factors Influencing Success in the Program's Online Courses, for an explanation of contrary findings with respect to teacher comments). For instance, adolescents were motivated to participate in RW, a social networking site, because of the different ways in which peers and mentors could provide them with feedback, which enhanced their willingness to create and share their media products (Chap. 9, Exemplar 1: Collaboration With a Social Networking Application). Trust is required to share work with others who provide feedback that could potentially be negative. The mechanisms that supported trust and collaboration in RW involved having multiple resources: partners, networks, media, and contexts for sharing, communicating, and evaluating. Brennan and Resnick (Chap. 17, Exemplars) present evidence that feedback from peers in Scratch supports imagining, creating, playing in addition to sharing and reflecting, all of which are involved in designing iteratively in this environment.

The nature of the feedback can also make a difference. For instance, specific teacher feedback was more effective than general comments in assisting students to substantially revise their work in WISE because the feedback pinpointed precisely the aspect of a visualization that needed to be reconsidered, thereby signaling what was relevant (Chap. 5, Impacts of MODELS and TELS on Teaching and Student Learning with Visualizations). Finally, the feedback that teachers gain when they closely examine student responses to assessments and reflect on the reasons for students' inaccurate explanations can lead to insights that result in improvements to their pedagogical practices, particularly if this task was done with colleagues.

In summary, finding a balance between structuring learning and allowing students to experience complexity is challenging. We need to provide sufficient resources to sustain students' productive engagement while at the same time nurturing their creativity. In addition, we prefer to reduce the mental burden associated with a complex learning environment without sacrificing a vital feature of the environment (e.g., immersive quality), clarity of content, or rich learning opportunities. Moreover, the nature of emerging technologies results in high learning demands in that multiple activities are required, such as working collaboratively and building a collective knowledge base with different partners over time, as well as making sense of content and engaging in problem solving. This situation means that some aspects of learning, collaboration, reflection, and creativity must be supported in some way.

Impact on Pedagogical Practices

So far, this volume suggests that we can be fairly optimistic about the positive impacts of technology integration on student outcomes. However, teachers are also concerned about how such integration will affect existing pedagogical practices (Collins & Halverson, 2009). As demonstrated in this volume, the extent of changes to pedagogical practices depends upon the nature of the technology being integrated. Minimal changes are needed when technology is used to supplement instruction or for students to apply what they learned. Nelson et al.'s virtual world, Scientopolis, serves this purpose; it is used to assess middle school students on the content they learned in class at various points throughout the year (i.e., students use their science knowledge to identify factors that explain agricultural and climate problems present in the virtual city and surrounding area) (Chap. 14, Exemplar 1: SAVE Science).

Requiring that students insert examples in a wiki for the class to use as an activity is another example (Chap. 7, Teaching and Learning With Web 2.0 Technologies). Although pedagogical adjustments are minimal in these instances, the onus is on designers to ensure that the technology is appropriate for the curriculum, learning goals, and diverse students. This is an ambitious task.

In truth, emerging technologies rarely fit perfectly into a curriculum, suggesting that the co-opting strategy for technology integration (Collins & Halverson, 2009) is seldom appropriate (i.e., technologies that support existing curricular outcomes and instructional organization). Emerging technologies often require conceptualizing content in a new way, which necessitates some change to practice. For instance, they might push the limits of teachers' own content knowledge and elicit alternative ways of student thinking that teachers may be unprepared to address. Nonetheless, it is possible to integrate technology without extensive changes in pedagogy. In White's (Chap. 6) work, for example, teachers integrated handheld, networked calculators to display multiple representations in conjunction with practices they regularly used, namely, whole-class and small-group discussions. In other words, the activity structure for integrating the technologies mimicked existing classroom structures. The teachers had to learn how to sequence the activities in a mathematically meaningful way and how to navigate from one structure to the other with the technologies. However, major changes to existing pedagogical practices were unnecessary.

Similarly, Vahey et al. (Chap. 2) focused on the key innovation (i.e., dynamic representations produced through SimCalc visualizations) while keeping other aspects invariant (e.g., instructional approach, format of materials) in the professional development (PD) they offered to mathematics teachers. Recognizing the teachers' preference for classroom interactions and their desire to continue using existing approaches, Vahey et al. presented a new routine (i.e., predict, check, and explain) to students in the form of guiding questions that were embedded in the paper materials they used. In this way, teachers had flexibility on how these questions were addressed (e.g., in small groups or as a whole class) thereby enabling them to teach in their preferred style. In addition, the materials were not in digital form because modifying the format while introducing a new technology would involve further alterations to practices (e.g., grading work on a new medium). These decisions were made to avoid delays in integrating visualization tools in the classrooms, which the authors argue is a risk when too many elements must be modified simultaneously, particularly when integration occurs in a short curriculum unit.

Most technologies require extensive shifts in pedagogy because integrating them in a widespread manner substantially changes the roles of teachers and learners (Dede, 2011). Mouza and Cavalier, for instance, describe how integration of laptops with Internet access enabled vocational high school students to immediately answer their own questions, thereby changing the relationship they had with their teacher as well as the quality and nature of classroom discussions (see Chap. 10, Laptops and Transformation of Classroom Instruction). Further, extending the boundaries of the curriculum and the range of teachers' pedagogical practices may be vital to capitalizing fully on an emerging technology's features and functions, especially when these aspects require interdisciplinary disciplinary knowledge, extensive collaborations, and complex problem solving on the part of learners. Web 2.0 tools, mobile technology, gaming, and virtual worlds provide such opportunities thereby necessitating a new vision of education.

Slotta and Najafi (Chap. 7) and Kyza (Chap. 8) show that integration of Web 2.0 tools, which provide extensive opportunities for communication and collaboration, requires embracing the idea that learning is about forming communities in which students share and build upon each other's knowledge, and in the process evaluate and edit the work of others. As Greenhow and Li (Chap. 9), Fields and Kafai (Chap. 16), and Brennan and Resnick (Chap. 17) demonstrate, these activities are common in informal learning environments (e.g., social network sites, virtual worlds, and games) where students make comments, vote, and modify others' work. However, collaborative knowledge-building opportunities tend to be limited in formal settings. Moreover, the idea of continuing this community over an extended period of time (i.e., semesters or years), as was done in the graduate seminar Slotta and Najafi described, is unknown to most educators.

Mobile technologies (see Chaps. 12 and 13) and games (see Chaps. 16 and 17) also require a reconceptualization of education as they help students overcome geographical and temporal barriers so that learning occurs anywhere and anytime. Consequently, the outside world becomes the classroom beyond schooling hours just as it can be brought into the classroom. Moreover, such technologies often involve the use of twenty first century skills. Thus, opportunities for learning are limitless but teachers need to tap into the benefits of informal learning for enhancing formal learning (Thomas & Brown, 2011). This possibility necessitates a transformation of teaching and learning practices, which can be greatly facilitated through PD.

In this volume, PD efforts to support teachers were discussed in two chapters involving visualization tools. Two features they shared was a focus on the content the technology aimed to enhance (i.e., mathematics and science) and opportunities for engaging in activities (i.e., teachers engaged in learning activities as students before shifting to teacher mode, see Chap. 2, Exemplar 2: Geometer's Sketchpad and teachers regularly scrutinized student responses on assessments as part of curriculum planning, see Chap. 5, Exemplars), both of which are key to the success of PD (Garet, Porter, Desimone, Birman, & Yoon, 2001). Moreover, Gerard et al. found that the science teachers receiving PD significantly changed two areas of their practice: assessment and whole-class discussions (Chap. 5, Exemplars). These improvements translated to significant student achievement gains and in-depth understanding, particularly for learners whose teachers received intensive PD (i.e., a 1-week summer institute over a period of 5 years). The extent of the gains is a key consideration given the pressure of high-stakes testing in the U.S. Investing in intensive PD may be worth the cost (Garet et al., 2001).

Although the exemplars in most chapters did not focus on PD, many authors addressed this issue in the "Next Steps" section, suggesting elements that should be considered in PD. For instance, classroom management was raised in several chapters (e.g., Chap. 10, Discussion and Next Steps) and other scholars propose that it be addressed in PD (Means, 2010). Support for how to modify pedagogy and curricula so that emerging technologies, which run counter to existing practices, can be integrated was also discussed. Ongoing research is needed to determine to what extent certain elements should be emphasized and how to address challenges that may be unique to certain technologies. Classroom management concerns, for instance, are especially salient when considering mobile devices. However, Squire suggests that these issues are minimized when students are engrossed in meaningful and substantive learning experiences (Chap. 13, Exemplar 3: Mobile Design Workshop) and van't Hooft points to research showing that mobile devices actually reduce the need for dealing with misbehaviors (Chap. 12, Status of Research on Mobile Learning Effectiveness). If this outcome is substantiated in future research, then effective design of learning activities may be a more prominent feature of PD than classroom management. The weight of each element may also change based on teachers' previous experiences with integrating technologies and their pedagogical preferences.

Next Steps

Three pressing and challenging issues must be addressed to ensure full technology integration in the future: (a) copyright, privacy, and safety concerns; (b) ecology receptive to a new culture of learning; and (c) assessment. The copyright issue is salient in learning situations where students build onto the designs of others (see Chaps. 4, 12, 16, and 17), which is referred to as *remixing*, or in knowledge-building activities where students collaborate and edit contributions to a group product (see Chaps. 7 and 8). Privacy and security concerns arise when students have unlimited access to the Internet, which occurs with mobile devices, thereby giving them access to social networking sites as well as others.

The copyright, privacy, and safety issues will continue to exist as technologies evolve. The current strategy of condemning emerging technologies, such as social networking media and mobile technologies, and banning them from schools (Collins & Halverson, 2009) because they are viewed as disruptive is unwise and unproductive. Children will be vulnerable as they continue to engage with these technologies on their own. As authors (e.g., van't Hooft and Greenhow and Li) have indicated, it is vital that we provide students with instruction on appropriate online conduct and responsible and ethical use of emerging technologies. Further, these are key technological literacy skills required for the twenty first century (Trilling & Fadel, 2009). Greenhow and Li suggest that teachers can collaborate with library media specialists who are trained to teach these skills, which would enable small-scale integration of social networking media in school. Slotta and Najafi suggest that a more comprehensive solution is needed that involves creating a new ecology for learning centered on social and cooperative principles, where ethical and responsible conduct can easily become the norm.

The second challenging issue involves creating an ecology that is receptive to a new culture for learning. In this new culture learners take advantage of resources outside of the classroom to learn, collaborate, reflect, and create (Thomas & Brown, 2011). This situation has resulted in students having higher expectations of the learning experiences they obtain in classrooms (Trilling & Fadel, 2009) where they look forward to being the agents in the learning process. This is typically not how current classrooms are organized, and hence, the need to create a new ecology that reflects the social realities outside the classroom. Altogether, the authors in this volume suggest that this ecology would have the following characteristics: (a) co-teaching or team teaching in middle and high school would be prevalent as much of the learning would naturally expand to various disciplines; (b) the pedagogy would be driven by the students based on their interests, goals, and needs; (c) content would be interdisciplinary; (d) students would collaborate with a variety of individuals (e.g., peers, mentors, experts, teachers) and learn effective communication and collaboration skills during teachable moments that arise during the process; and (e) assessments would provide students with opportunities to demonstrate the twenty first century skills they acquired, including digital literacy skills, and they would do so in multiple learning contexts and at multiple points throughout the year so that a comprehensive profile of student learning is available. Of course, this ecology must be endorsed and supported by administrators.

The third challenge is assessment. Ultimately, the ecology and assessment issues are intricately intertwined, especially in the U.S. where the intense pressure associated with testing drives much of what happens in classrooms. Consequently, there tends to be a sense among educators and administrators that there is no room for twenty first century skills in the curriculum. They are therefore often not taught, and if they are, narrow measures that target basic knowledge and skills are used, which do not reflect the complex learning that occurred. Thus, as several authors argue (e.g., Greenhow & Li, Squire, van't Hooft), a critical goal is to create assessment systems that capture complex learning, document changes in learning over time, and monitor learning that occurs outside the school building and links it to a school's data system. Emerging technologies, such as wikis and social networking sites, have a built-in capacity that tracks individual's actions, which could serve as a data source. One fruitful area of development would be to design emerging technologies with these features so that collecting data is easy. However, it must also present the data in a form that enhances the teachers' ability to interpret the results. Given the emphasis on data-driven decision-making, it would behoove us to develop and integrate technologies that support teachers' work and also enable teachers and administrators to make informed decisions. Moreover, an infrastructure for collecting data over multiple settings would need to be created to make all this viable.

In conclusion, designing or integrating emerging technologies is challenging given the complexity of the educational system. Conducting research on the effectiveness of such technologies within this system coupled with the pace with which technological innovations are produced can also seem daunting. However, meeting goals for the twenty first century is possible particularly if there is systematic coordination amongst stakeholders in education including educators, administrators, researchers, instructional technologists, curriculum and instructional designers, policy makers, and learners. We, as educators and scholars, should expand our own knowledge-building communities so that our efforts are coordinated to provide rich, challenging, engaging, and mind opening learning experiences that are supported in ways that children and youth need to flourish. Ultimately, this knowledge-building goal is the purpose of the book series, *Explorations in the Learning Sciences, Instructional Systems, and Performance Technologies*, in which this volume is included.

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About the Authors

Robert Q. Berry III is an associate professor of mathematics education at the Curry School of Education. His research interests focus on equity issues in mathematics education, computational estimation, and teachers' mathematics content knowledge. His professional affiliations include National Council of Teachers of Mathematics (NCTM), National Council of Supervisors of Mathematics (NCSM), Association of Mathematics Teacher Education (AMTE), Benjamin Banneker Association (BBA), Virginia Council of Teachers of Mathematics. Currently, he serves on the editorial panel of NCTM's journal, Teaching Children Mathematics, NCSM Equity Committee, and editor of the BBA newsletter, Banneker Speaks. In addition, he is on the editorial board for the Urban Review and the Journal of Educational Foundations.

Karen Brennan is a Ph.D. candidate at the MIT Media Lab, a member of the Scratch Team, and leads the ScratchEd project. Her research is primarily concerned with the ways in which learning communities support computational creators. More concretely, her work focuses on Scratch and the Scratch educator community, studying how participation in the Scratch online community and how professional development for educators can support young people as creators of computational media. Prior to joining Media Lab, Karen completed degrees in Computer Science, Mathematics, and Curriculum Studies at the University of British Columbia in Vancouver, Canada. She has more than 10 years of teaching experience in secondary and post-secondary computer science and mathematics, and post-secondary teacher education, including curriculum and instructional methods.

Glen Bull is a professor of instructional technology in the Curry School of Education. He serves as co-director of the Center for Technology and Teacher Education. He developed one of the nation's first statewide K-12 Internet systems, Virginia's Public Education Network (PEN). He is a founding member and past president of the Society for Information Technology and Teacher Education (SITE), and a recipient of the Willis Award for "Outstanding Lifetime Achievement in Technology and Teacher Education." He currently provides leadership for the National Technology Leadership Coalition, a consortium of national teacher educator associations and

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national educational technology associations. He serves as editor of Contemporary Issues in Technology and Teacher Education, a peer-reviewed journal jointly sponsored by five professional associations representing science education (ASTE), mathematics education (AMTE), English education (CEE), social studies (CUFA), and educational technology (SITE).

Albert R. Cavalier is an Associate Professor of Special Education in the College of Education and Human Development (CEHD) at the University of Delaware where he teaches pre-service and in-service teacher preparation courses in assistive technology, classroom management, and positive behavior supports. Dr. Cavalier has also assisted in the design and implementation of the Delaware statewide Positive Behavior Support Initiative and serves on the Governor's Advisory Council for Exceptional Citizens. He is currently the principal investigator of two research grants. One grant involves studying the efficacy of office discipline referrals for students with behavioral challenges in public schools and the other studies the effects of skilled therapy dogs on the classroom participation and social skills of students with autism spectrum disorders. Recent co-authored publications include an evaluation of self-management strategies with children with learning disabilities, a review of best practices in student discipline, an evaluation of ubiquitous laptop computing by adolescents with intellectual disabilities in vocational/technical programs, and an investigation of the photovoice methodology with children with autism spectrum disorders. Dr. Cavalier has received a national award for computer design and development from The National Science Foundation and The Johns Hopkins University, a Certificate of Recognition for inventive contribution from the National Aeronautics and Space Administration, and the Distinguished Faculty Award in CEHD at the University of Delaware.

Cathy Cavanaugh is an Associate Professor of Educational Technology specializing in instructional design, and online and blended learning environments. Her funded research includes studies of classroom technology and professional development, effective practices in virtual schools, and design of online professional development, courses and programs. She has authored, co-authored, or edited numerous books and chapters, journal articles, and papers in the educational technology field. She received the first research award given by the International Association for K-12 Online Learning in 2009 and she served as a Fulbright Senior Scholar to Nepal in 2010. Prior to her academic appointments, Cathy was a secondary science teacher, a teacher professional development coordinator, and an assistant director of the Florida Center for Instructional Technology.

Jennifer L. Chiu is an assistant professor of Science, Technology, Engineering and Mathematics (STEM) Education in the Curry School of Education at the University of Virginia. She investigates how students learn from technology-enhanced curricula in authentic classroom settings, how students monitor their understanding in computer-based environments, and how to support student learning with dynamic visualizations through generative activities and instructional design patterns. Formerly, Jennifer was an engineer and high school mathematics and science teacher. She currently teaches undergraduate and graduate courses in STEM education.

Stephanie Corliss is the Research Coordinator at the Center for Teaching and Learning at the University of Texas at Austin. She collaborates with faculty, staff, and administration in conducting educational research related to student readiness and achievement and the effectiveness of instructional innovations. She previously worked at the University of California, Berkeley, where she led professional development, research, and assessment efforts with middle school teachers integrating technology-enhanced instruction into their curriculum. She has a Ph.D. in Educational Psychology focused on learning, cognition, and instruction; a master's degree in Educational Psychology focused on program evaluation; and a bachelor's degree in Psychology from The University of Texas at Austin.

Susan Courey is an Assistant Professor in the Special Education Department at San Francisco State University. Dr. Courey is the Mild/Moderate Program Coordinator and specializes in preparing effective teachers for diverse urban classrooms. Her research interests include teacher preparation and teaching mathematics to students with learning challenges. She represents one of the first universities to be awarded a coveted 325T program Improvement Grant from the Office of Special Education Programs. Prior to her current appointment, Dr. Courey worked on mathematics problem solving with Lynn Fuchs, Ph.D. at Vanderbilt University, where she was awarded the Robert Gaylord-Ross Award for Excellence in Scholarly Writing.

Deborah A. Fields is an Assistant Professor in the College of Education and Human Services at Utah State University. Her research focuses on the intersections of children's lives: between personal and academic interests, identity and learning, and across different social settings (home, school, friends, hobbies). These interests have guided her studies in virtual worlds and STEM (science, math, engineering & math) education in and across classrooms, clubs, and digital social environments. She is currently studying issues of aesthetics, learning, and gender in children's designs with digital technologies, specifically with computational textiles and computer programs made with Scratch. She has led many workshops on Whyville, Scratch, and electronic textiles with elementary, middle, and high school students. In addition, she has helped teach a number of courses for future educators in inclusive learning as well as educational technology. Fields' work has been published in a number of peer-reviewed journals, including the *International Journal of Computer Supported Collaborative Learning, Games and Culture,* the *International Journal of Science Education*, and *On Horizon.* Fields earned a doctorate in Psychological Studies in Education from the University of California, Los Angeles.

Cecile Foshee is an Educational Technology doctoral student at Arizona State University. She is also an assistant professor at the Art Institute of Phoenix. She has 11 years of educational related experience, from teaching to designing and developing instructional materials. Cecile is part of the design team on the SAVE Science project, for which she focuses on developing visual assets for the project.

Libby Gerard is a Research Scientist at the University of California, Berkeley. She investigates teacher and principal development in technology-enhanced learning environments, and examines the relationship of professional development to students' development of understanding. She is particularly interested in how teachers and principals use technology-enhanced assessment data to customize instructional decisions. Libby leads professional development activities including summer institutes, sustained inquiry-based communities, and teacher mentoring. She received her doctorate from Mills College as a Fellow with a National Center for Teaching and Learning, and recently completed a Post Doctoral Fellowship at UC Berkeley with the Technology-Enhanced Learning in Science Center (http://telscenter.org).

Christine Greenhow is an Assistant Professor of learning technologies in the Department of Educational Psychology at Michigan State University. Her research focuses on learning in social media contexts, such as online social networks, from learning sciences and new literacy studies perspectives, and with the goal of improving theory, practice, and policy. Her work aims to (a) increase our understanding of the intellectual and social practices occurring in online, popular culture-inspired environments, (b) analyze how those practices align, contradict, or herald strategies, skills, and dispositions valued in formal education, and (c) use these insights to design more engaging spaces for learning and professional development. Formerly an Assistant Professor at the University of Maryland and a former high school teacher, Christine completed postdoctoral work at the *University of Minnesota, where she won the university's Outstanding Postdoctoral Scholar Award* for scholarly achievement. She was a visiting fellow at the Information and Society Project at *Yale University* and is currently working on a book about social media, global education, and policy. Her work has been featured in *local, national, and international news media.* She has been active in educational reform efforts and is the co-founder of an award-winning *educational non-profit*.

Yasmin B. Kafai is a Professor of Learning Sciences at the Graduate School of Education at the University of Pennsylvania. Her research focuses on the design and study of new learning and gaming technologies in schools, community centers, and virtual worlds. Book publications include "Beyond Barbie and Mortal Kombat: New Perspective on Gender and Gaming" (MIT Press) and "The Computer Clubhouse: Constructionism and Creativity in Youth Communities" (Teachers College Press). Her work includes collaborations with MIT researchers that have resulted in the development of Scratch, a popular media-rich programming environment for designers of all ages, to create and share games, art, and stories. Current projects examine creativity in the design of computational textiles with urban youth. Dr. Kafai earned a doctorate from Harvard University while working at the MIT Media Lab.

Diane Jass Ketelhut is an Associate Professor of Science Education at University of Maryland, College Park. Her research interests center on improving student learning and engagement with science through increasing access to scientific inquiry experiences and through raising self-efficacy in science. She looks specifically at the use of virtual environments to deliver scientific inquiry curricula and science assessments to students in the classroom, and at professional development to help teachers integrate scientific inquiry into their curricula. She is the Principal Investigator of the SAVE Science project. She holds certification in secondary school science and was a science curriculum specialist and teacher (science and mathematics) for Grades 5–12 for 15 years. Prior to that, she conducted immunology basic research for 2 years. Diane received a B.S. in Bio-Medical Sciences from Brown University, an M.Ed. in Curriculum and Instruction from the University of Virginia, and her doctorate in Learning and Teaching from Harvard University.

Younsu Kim is a Mathematics Education Ph.D. student at Arizona State University. She is currently involved in a development, testing and delivery, and maintenance of the SAVE Science modules. She is interested in students' mathematical thinking, motivation, cognitive load theory, and game design.

William Kjellstrom is the director of the Technology Infusion Program and a graduate fellow in the Center for Technology and Teacher Education at the University of Virginia. His primary research interest involves the study of emerging technologies that support student learning in elementary classrooms. William currently teaches a technology integration course for pre-service teachers in the Curry School of Education, and he also works with a number of elementary schools in Virginia that are implementing digital fabrication systems. He is a former elementary school teacher, instructional technology resource teacher, and technology coordinator. William was the recipient of the 2010 Outstanding Graduate Teaching Assistant for his work with pre-service and in-service teachers.

Jennifer Knudsen is a Senior Mathematics Educator in The Center for Technology and Learning (CTL) at SRI International. Ms. Knudsen designs curricular materials and professional development programs to promote greater access to important mathematics for all students. She works on a variety of CTL's mathematics education projects, including the Scaling Up Simcalc, SunBay, and Cornerstone Mathematics programs. Previously, Ms. Knudsen developed technology-integrated, context-rich middle school mathematics programs for teachers, students, and parents at the Institute for Research on Learning. She was a high school mathematics teacher in New York City's public schools.

Eleni A. Kyza is an Assistant Professor in Information Society at the Cyprus University of Technology. Her work focuses on the design and research of new technologies to support teaching and learning at the elementary and secondary school level. Through her involvement in European funded projects, such as projects CoReflect and PROFILES, she has worked extensively with science education teachers interested in integrating new technologies to support inquiry-based learning and teaching. Using the STOCHASMOS web-based platform, Dr. Kyza has been involved in design-based research in close collaboration with teacher design teams seeking to understand how technology mediates and supports collaborative learning in authentic classroom environments. Dr. Kyza holds a Ph.D. degree from the Learning Sciences program at Northwestern University with a specialization in Cognitive Science, a masters' degree in Technology in Education from the Harvard Graduate School of Education, a B.Sc. in Education, summa cum laude, with a concentration in Educational Media and Technology from Boston University, and a Teacher's Diploma from the Pedagogical Academy of Cyprus. Her undergraduate and graduate studies were funded through CASP/Fulbright scholarships. Her post-doctoral studies with the Learning in Science Group at the University of Cyprus were funded through a European Commission IRG Marie Curie Fellowship and by the Cyprus Research Promotion Foundation.

Teresa Lara-Meloy is a Mathematics Education Researcher in The Center for Technology and Learning at SRI International. Ms. Lara-Meloy designs curriculum and professional development opportunities for students, teachers, and professional development leaders, most recently for the SunBay and Cornerstones Mathematics programs. She has designed workshops for professional development providers, teacher workshops using SimCalc, created a 15-week for middle school girls to design their own computer game, and co-designed an intensive summer workshop for middle school teachers on argumentation in coordinate geometry. Prior to working at SRI, Ms. Lara-Meloy was a technical assistance provider for the America Connects Consortium at EDC and a mathematics researcher with TERC. A dual citizen, she also has recent experience working and teaching in Mexico.

Nancy C. Lavigne is an Associate Professor in the School of Education at the University of Delaware. Her research focuses on students' problem solving and reasoning on tasks that require application of statistical knowledge, and using the research on students' thinking to design environments that foster and enhance learning in STEM. She is a member of the *International Society for the Learning Sciences,* the *American Educational Research Association,* and the *National Council of Teachers of Mathematics*. She received her M.A., and Ph.D. degrees in Educational Psychology at McGill University in Montréal, Québec, Canada and conducted post-doctoral work at the Learning, Research, and Development Center (LRDC) at the University of Pittsburgh.

James C. Lester is Professor of Computer Science at North Carolina State University. His research in intelligent tutoring systems, computational linguistics, and intelligent user interfaces focuses on intelligent game-based learning environments, affective computing, and tutorial dialogue. He received the B.A., MSCS, and Ph.D. degrees in Computer Science from the University of Texas at Austin, and the B.A. degree in History from Baylor University. He has served as Program Chair for the ACM International Conference on Intelligent User Interfaces and the International Conference on Intelligent Tutoring Systems. He is Editor-in-Chief of the *International Journal of Artificial Intelligence in Education.*

Jiahang Li is a Ph.D. Candidate in Reading Program in the College of Education at the University of Maryland College Park. He earned his B.A. and M.A. degrees from Department of Chinese Language and Literature at Peking University in China. His research interests include pre-service teacher education, multicultural literature, educational technology, social media, and teaching Chinese language and culture. He also works for the STARTALK project at National Foreign Language Center and is in charge of a variety of tasks including analyzing and reviewing STARTALK programs' data, assisting and tracking programs' implementation, and conducting site visits. As an instructor at Confucius Institute at Maryland and International College for Chinese Studies at Peking University, he has years of experiences in teaching K-12 students, as well as undergraduate and graduate college students at University of Maryland College Park.

Marcia C. Linn is a Professor at the Graduate School of Education at the University of California, Berkeley. She is a member of the National Academy of Education, and a Fellow of American Association for the Advancement of Science (AAAS), American Psychological Association, and Association for Psychological Science. Dr. Linn was elected President of the International Society of the Learning Sciences, Chair of the AAAS Education Section, and member of the AAAS Board. She received the National Association for Research in Science Teaching Award for Lifelong Distinguished Contributions to Science Education and the Council of Scientific Society Presidents first award for Excellence in Educational Research.

Feng Liu is a Post Doctoral Associate at the University of Florida (UF)'s College of Education. His current research interests include the employment of advanced research methods and statistical approaches in education and social science fields, technology integration in school learning environments specifically in Science, Technology, Engineering, & Mathematics (STEM)-related areas, online learning success and the effectiveness of virtual schooling, and e-game/simulation in education. He has several publications in these areas. Dr. Liu has extensive research experience in the investigation of success in K-12 virtual learning environments. He received a Ph.D. degree from UF in Educational Technology with a minor in Research Evaluation & Methodology and is a member of *Association for Educational Communications and Technology*, American Educational Research Association, and American Evaluation Association.

Ou Lydia Liu is Research Scientist at the Educational Testing Service (ETS). She holds a doctorate in Quantitative Methods and Evaluation from the University of California, Berkeley. Her research interests include item-response modeling, development and validation of K-12 innovation science assessment, and outcomes assessment in higher education. Lydia has published extensively in applied measurement and science education journals. In recognition of her independent and extensive research, Lydia received the 2011 NCME Jason Millman Promising Measurement Scholar Award.

Bradford W. Mott is a Research Scientist in the Department of Computer Science at North Carolina State University. He received the B.S., MCS, and Ph.D. degrees in Computer Science from North Carolina State University. He oversees research and development on several advanced learning technology projects, including Crystal Island, an intelligent game-based learning environment that was first launched as part of his dissertation research. Prior to joining NC State, he led development efforts on Gamebryo, a cross-platform 3D game engine used extensively in the digital entertainment and training industries, for the Nintendo Wii at Emergent Game Technologies.

Chrystalla Mouza is an Associate Professor of Instructional Technology in the School of Education at the University of Delaware. She earned an Ed.D., M.Ed, and M.A. in Instructional Technology and Media from Teachers College, Columbia University and completed post-doctoral work at the Educational Testing Service (ETS). Her research investigates teacher learning with regard to technology, applications of technology in K-12 classrooms, and teaching and learning outcomes in ubiquitous computing environments. Her work has been supported by the National Science Foundation, the Delaware Department of Education through the Higher Education Component of No Child Left Behind, and ETS. Dr. Mouza is the recipient of the 2010 Distinguished Research in Teacher Education Award from the Association of Teacher Educators and former Chair of the AERA Special Interest Group, *Advanced Technologies for Learning*. She serves on the editorial board of the *Journal of Technology and Teacher Education* and provides editorial assistance to numerous journals, conferences, and book publications including the *Journal of the Learning Sciences*, the Annual Conference of the *American Educational Research Association*, and the *Research Highlights in Technology and Teacher Education* book series.

Elizabeth Murray is a Senior Research Scientist at CAST, where she applies her technical skills, mathematics background, special education experience, and clinical specialties in applying Universal Design for Learning (UDL) to technology-based educational materials and instruction. Dr. Murray is Co-Principal Investigator for "Learning Progressions: Developing an Embedded Formative and Summative Assessment System to Assess and Improve Learning Outcomes for Elementary and Middle School Students with Learning Disabilities in Mathematics" and served as Co-Principal Investigator for "Principled Science Assessment Designs for Students with Disabilities."

Hedieh Najafi completed her Ph.D. at The Ontario Institute for Studies in Education in 2012. She received her undergraduate degree in computer engineering at Shahid Beheshdi University, in Tehran and then completed a Masters' degree in technology studies in education at the University of British Columbia. She has interests and experience in online, K-12, and graduate education. Her doctoral research investigates a pedagogical model of collective inquiry through a design-based study of a high school biology curriculum in climate change science.

Brian C. Nelson is an Associate Professor of Educational Technology in the School of Computing, Informatics, and Decision Systems Engineering at Arizona State University. Dr. Nelson's research focuses on the theory, design, and implementation of computer-based learning environments, focusing on immersive games. An instructional designer and learning theorist, he has published and presented extensively on the viability of educational virtual environments for situated inquiry learning and assessment. Dr. Nelson's recent publications have addressed issues related to the design and evaluation of educational games, with a focus on situated cognition and socio-constructivist-based design. Dr. Nelson was the Project Designer on the River City Virtual World project through two NSF-funded studies, and is a Co-Principal Investigator on the on-going NSF-funded SAVE Science and SURGE studies. He was recently co-PI on two MacArthur Foundation grants: Twenty-first Century Assessment, investigating new models for assessment in digital media-based learning environments, and Our Courts, creating and assessing an immersive game to promote civic engagement. Dr. Nelson earned his doctorate at Harvard University in 2005.

Charles Patton is a Principal Scientist of the Center for Technology in Learning (CTL) at SRI International. After completing his Ph.D. in the mathematics of quantum gravity at Stony Brook with additional work at Oxford's Mathematical Institute, Dr. Patton was struck with a compelling vision of how handheld devices could be designed to radically democratize access to the concepts of mathematics. Since that time, at HP, with Texas Instruments, through NSF grants, and now, at SRI, he has been fully engaged in researching, fostering, and inventing the future of handhelds in education. At CTL, Dr. Patton is helping build a technology bridge from research to practice, while fostering the uptake of learning science insights in a number of SRI's technology programs.

Ken Rafanan is a Research Social Scientist at the Center for Technology in Learning at SRI International. His work focuses on the development and evaluation of programs that integrate technology, curricula, and teacher professional development for mathematics learning, most recently for the SunBay and Cornerstones Mathematics programs. Mr. Rafanan has contributed to the development of tablet-based math learning applications for pre-school classrooms, developed and implemented a handheld technology-delivered curriculum focused on rational number in elementary school classrooms, and developed technology-supported curricula and formative and summative assessments on proportional reasoning in middle school classrooms in the United States and Europe. Mr. Rafanan has also had the honor of leading professional development workshops with both elementary and middle school teachers.

Mitchel Resnick is a Professor of Learning Research at the MIT Media Lab. He develops new technologies and activities to engage people (especially children) in creative learning experiences. His Lifelong Kindergarten research group developed ideas and technologies underlying the LEGO Mindstorms robotics kits and Scratch online community, used by millions of young people around the world. He also co-founded the Computer Clubhouse project, an international network of 100 after-school learning centers where youth from low-income communities learn to express themselves creatively with new technologies. Dr. Resnick earned a B.S. in physics from Princeton, and an M.S. and Ph.D. in computer science from MIT. He worked for 5 years as a science-technology journalist, and he has lectured and consulted around the world on innovative uses of new technologies in education. In 2011, he was awarded the McGraw Prize in Education and also the World Technology Award in Education.

Jeremy Roschelle is a co-Director of the Center for Technology in Learning (CTL) at SRI International. Dr. Roschelle's research examines the design and classroom use of innovations that enhance learning of complex and conceptually difficult ideas in mathematics and science. Two running themes in his work are the study of collaboration in learning and the appropriate use of advanced or emerging technologies (such as component software and wireless handhelds) in education. More recently, Dr. Roschelle has been addressing large-scale use of innovative technologies in education, both through consulting to companies with a large impact in the market and through implementation research on scaling up SimCalc to a wide variety of teachers and classrooms.

Jonathan P. Rowe is a doctoral candidate in the Department of Computer Science at North Carolina State University. His research focuses on intelligent tutoring systems, user modeling, and interactive narrative in game-based learning environments. He received the M.S. degree in Computer Science from North Carolina State University and the B.S. degree in Computer Science from Lafayette College. He served as a co-organizer for the Fourth Workshop on Intelligent Narrative Technologies. His research has been recognized with a best paper award at the Seventh International Artificial Intelligence and Interactive Digital Entertainment Conference and best paper at the Second International Conference on Intelligent Technologies for Interactive Entertainment.

Kent Slack is an Educational Technology Ph.D. student at Arizona State University. He was the lead programmer and developer of the SURGE project. His current interests involve cognitive load theory in educational game contexts, the use of instructional design methods in higher education settings, and Merrill's first principles of instruction. Dr. Slack is involved with the programming, development, testing, delivery, and maintenance of SAVE Science.

James D. Slotta is an Associate Professor of education in the Ontario Institute for Studies in Education (OISE) at The University of Toronto. As Canada Research Chair in Education and Technology, his research employs technology-enhanced environments to investigate cognitive models of learning and instruction. Recently, he has advanced a new pedagogical model called Knowledge Community and Inquiry where students are engaged in social forms of inquiry learning using advanced technologies to support their interactions with peers and collective advancement of knowledge. Dr. Slotta's group has been collaborating with several other teams internationally to develop the Scalable Architecture for Interactive Learning (SAIL), an open source technology framework that supports the design of smart classrooms and distributed learning environments.

Michele Spitulnik is the Director of Science Education and Middle School Teacher at the Contra Costa Jewish Day School. She is engaged in designing and implementing inquiry-based science curriculum. She received her doctorate in science education from the University of Michigan and held post-doctoral and research scientist positions at the University of California, Berkeley. Michele's research interests include designing curricula and technological tools to support science learning and designing and conducting professional development programs to support teachers in implementing inquiry-based science.

Kurt D. Squire is the Acting Director of the Educational Research Integration Area in the Morgridge Institute for Research and an Associate Professor in Curriculum & Instruction at the University of Wisconsin-Madison. He is the author of over 75 works on educational technology, including Video Games & Learning: Teaching and Participatory Culture in the Digital Age, published by Teachers College Press. Dr. Squire is also a founding member of the Games + Learning + Society Initiative.

Phil Vahey is a Senior Research Scientist at the Center for Technology in Learning at SRI International. Dr. Vahey's research focuses on the design of technologies and learning activities that enhance learning of conceptually difficult mathematics, and ways to scale systems that use these technologies and learning activities. His recent research has focused on the use of representationally rich computer-based materials for making the mathematics of change accessible to a diverse student population, and the development of tablet-based mathematics learning applications for pre-school classrooms. Dr. Vahey has been PI or Co-PI on several National Science Foundation funded projects, and leads the SunBay and Cornerstones Mathematics programs.

Mark van't Hooft has been a researcher and technology specialist for the Research Center for Educational Technology (RCET) at Kent State University since 2000. He engages in research and program evaluation, provides occasional technical support in the AT&T Classroom, and is the Editor of the *Journal of the Research Center for Educational Technology* (RCETJ). Dr. van't Hooft is also a founding member and former chair of the Special Interest Group for Mobile Learning (SIGML) for the International Society for Technology in Education (ISTE). His current research focus is on ubiquitous computing and the use of mobile technology in K-12 education, especially in social studies. Prior to his work at RCET, Dr. van't Hooft taught middle school and high school social studies and language arts. He holds a B.A. in American Studies from the Radboud Universiteit of Nijmegen, the Netherlands, and an M.A. in History from Texas State University. He received his Ph.D. degree with a dual major in Curriculum & Instruction and Evaluation & Measurement from Kent State University.

Keisha Varma is an Assistant Professor in the Department of Educational Psychology at the University of Minnesota. She was a member of the Learning Technology Center at Vanderbilt University and became an active member of the science education community via a post-doctoral fellowship with the Technology Enhanced Learning in Science (TELS) Center at the University of California, Berkeley. Keisha's current research focuses on the design and evaluation of curriculum materials that promote students' scientific reasoning skills. Additionally, she is interested in studying teacher knowledge development, exploring ways to leverage psychological methodologies to understand changes in teachers' pedagogical content knowledge and their representations of effective science teaching practice. Throughout her career, Dr. Varma has conducted research in elementary, middle, and high school classrooms. She introduced new technologies and teaching approaches and measured the connection between these innovations and student learning outcomes. She has also assisted in the design and implementation of technology-enhanced professional development programs for middle- and high school science teachers.

Tobin White is an Assistant Professor in the School of Education at the University of California (UC), Davis. He studies the use of technology in teaching and learning mathematics. His current research, using classroom networks of handheld calculators and computers, involves designing collaborative problem-solving tools and activities in order to investigate intersections between conceptual and social dimensions of mathematics learning. A former high school mathematics teacher himself, he has worked in mathematics teacher preparation programs for the last decade, first while a Ph.D. student at Stanford and now as a faculty member at UC Davis. In 2008, Dr. White received a prestigious Early Career Development (CAREER) award grant from the National Science Foundation.

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