Innovations in Science Education and Technology 21

Vincent C.H. Tong *Editor*

Geoscience Research and Outreach

Schools and Public Engagement

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Geoscience Research and Outreach

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Vincent C.H. Tong
Editor

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Editor
Vincent C.H. Tong
Department of Earth and Planetary Sciences
Birkbeck, University of London
London, UK

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University of London Vincent C.H. Tong

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Part I
Introduction: The Context

Geoscience and Educational Research in Outreach Activities

Vincent C.H. Tong

Geoscience is distinctly multidisciplinary and interdisciplinary. Geoscientists study the Earth as a system characterised by a myriad of vastly interconnected components, and they use a variety of scientific tools in their investigations. Physics, chemistry, biology, mathematics, computation and engineering principles are all employed in order to push the boundaries of our understanding of the planet Earth. Apart from the intrinsic scientific interest, geoscience research also informs social and economic policymaking at national and international levels and often has profound geopolitical impact as a result. From energy and water resources to natural disasters, and from changing climatic patterns to the evolution of the Earth's deep interior, geoscience research is central to our understanding of our home in the universe.

It is therefore hardly an exaggeration to claim that geoscience research affects people's lives in many ways and on different levels. Given the significance of knowledge about the Earth, geoscience outreach is both important and necessary. It is not difficult to understand the reasons when we think about the strong demand for knowledge and new findings from geoscience research. Here are a few examples. Let us first consider the public reactions to natural disasters such as tsunamis, earthquakes, hurricanes and volcanic eruptions. Such events are made known to many around the world with minimum delay as media outlets monitor and report them continuously. Individuals witnessing these events upload photos and video footage onto social media sites. Together with the coverage by the mass media, they have enormous followings and generate fervent discussions on the web. Research geoscientists are always in demand to explain our current understanding of these phenomena and their impact to the public in these occasions across different platforms.

V.C.H. Tong (✉)
Department of Earth and Planetary Sciences, Birkbeck, University of London, London, UK
e-mail: vincent.tong@ucl.ac.uk

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Apart from the general public, there are many specific groups of consumers of geoscience research. Policymakers need to be better informed about the effects of rising levels of greenhouse gases on temperature, precipitation patterns and the acidification of the oceans. School children are excited about the discovery of previously unknown species from new fossil records. Farmers want to understand the effects of changing climatic patterns, groundwater levels and soil composition in order to optimise crop yields. Television programmes about the Earth attract huge numbers of viewers around the world, and there are channels that specialise in producing and broadcasting documentaries featuring different natural phenomena of the planet. Geoscience research provides the scientific basis in these policymaking and educational contexts. There is a genuine need for many to be effectively informed about the latest findings in both pure and applied geoscience for a variety of reasons.

Outreach is important and necessary not only to those on the receiving end but also to the generators and providers of new scientific knowledge. Many geoscience professors and researchers are keen to widen the impact of their work beyond their peers in the academic world. Inspiring the general public and the next generation through one's research is, after all, immensely rewarding. To others, engaging in geoscience outreach may be a matter of meeting the conditions set by their research funders. But this trend of being accountable and socially responsible is clearly pointing in one direction: researchers are now increasingly asked to include detailed plans about their outreach programmes when they apply for research grants to carry out scientific investigations. It is also becoming common that geoscientists are requested to demonstrate innovations in their outreach activities. In many cases, funding for linked science outreach programmes is allocated alongside financial support for the geoscience research. Apart from academics and researchers, many museums, universities, learned societies and public organisations are also keen to showcase their work by using geoscience research as an effective way to engage with schools and the general public, to widen participation, as well as to justify the public funding they receive. Geoscience outreach is therefore driven by both demand and supply.

Although it may be viewed as an interactive process between educators and participants, outreach requires considerably more effort from the educators conducting the outreach activities. In particular, communicating the huge range of scientific discoveries about our planet and explaining the diverse array of scientific methods are never easy. Not to mention the challenge in engaging school children of different ages and the general public in both formal and informal settings. In order to accomplish these mammoth tasks, both established and emerging approaches to designing and implementing outreach programmes are called for. Many programmes are based on field, workshop and laboratory activities. Online approaches are also routinely used for reaching a wider audience and for exploiting new technological possibilities, and it is not unusual to adopt mixed methods involving all these approaches in a single programme.

How can we best facilitate and evaluate education based on geoscience research and knowledge? How can we design and implement effective outreach programmes?

How can we train school teachers in outreach activities and teach new geoscience findings to school children? These are important questions constantly asked by educators, including geoscience academics, school teachers and outreach programme directors and organisers, and are actively investigated by researchers working on geoscience education. Indeed, geoscience education research is an integral part of geoscience outreach. Geoscience academics and researchers are, therefore, by no means the only key contributors to research and outreach in geosciences. Informal educators, schoolteachers and science education researchers are vital in bringing geoscience research and outreach together.

As geoscience outreach involves contributors with different perspectives, how can we understand the relationship between geoscience research and outreach? Whilst outreach has the potential to influence geoscience research, it can be argued that outreach programmes are more likely to be based on or enhanced by geoscience research. How can outreach be enhanced by geoscience research? One of the traditional approaches may involve a scientist talking passionately about her/his geoscience research in an invited public lecture. However, this is a restrictive way of looking at outreach enhanced by scientific research. It is restrictive because of the limited type of contributor involved (i.e. scientist) and the limitations in the mode of communication (i.e. invited lecture). Perhaps more importantly, the question of how much value is attached to programme evaluation and pedagogical enhancement should be considered. A more inclusive view of the relationship between geoscience research and outreach should incorporate a broader understanding of the term ‘outreach’ as a form of research-enhanced education, which should ideally be characterised by the following elements:

1. Geoscience research findings and knowledge, or enquiry-based activities in geoscience are featured.
2. Geoscience researchers are actively involved in the programme design or implementation.
3. Educational research is conducted on geoscience outreach programmes or on how to evaluate and best support the pedagogy.

What is important is that both scientific research and educational research enhance school and public outreach. This framework reflects the view that outreach is an ultimate objective, rather than starting from geoscience researchers as the key contributor and bearing a perspective that is centred on scientific research. This model also marks a departure from the idea that outreach is (merely) one of the many ways of disseminating research findings. This ‘research-enhanced outreach’ model, as opposed to the ‘research dissemination model’, therefore views outreach as the goal with scientific and educational research employed to facilitate the activities. It is clear that pedagogical considerations and geoscience research are both key ingredients to effective outreach programmes and activities. Geoscience researchers themselves may act as educational researchers or educators at the same time in some outreach programmes. In other outreach projects, scientists and informal educators work with researchers who specialise in educational research. In other words, outreach based on or enhanced by geoscience research should involve building multiple identities (i.e. being a scientist and an educator at the same time) or forming cross-disciplinary, collaborative partnerships.

The objective of this book is to show how geoscientists, education researchers, school teachers, informal educators and outreach programme organisers from different countries have contributed to the design, implementation, evaluation and enhancement of outreach activities associated with a wide range of geoscience research. The intended readership obviously includes this group of scientists and science educators who are already active or interested in participating in geoscience outreach. But it is hoped that those from other academic disciplines as well as educators in the wider higher education community will find this book useful, too. Policymakers and research funders operating in the field of energy, natural resources, climate change, and other geoscience-related areas may also be interested in this book. Moreover, the chapters in this book are likely to be directly relevant to public organisations such as meteorological offices and natural hazards units. Whilst it is impossible to capture the full range of the types of work on geoscience research outreach in a single volume, this book aims to show some recent examples of innovative outreach approaches as well as challenges and recommendations for good practices in geoscience outreach. Together with the companion book entitled *Geoscience Research and Education: Teaching at Universities* (edited by Tong and published by Springer), this volume shows how geoscience research has played an important part in a wide spectrum of educational settings.

Two types of chapters are featured in this book: (1) full chapters showing innovative design and implementation in specific outreach activities or programmes and (2) shorter perspective chapters highlighting current trends, challenges and solutions on more general issues in geoscience research and outreach. A bullet-point overview appears towards the end of all chapters for easy references to the key points discussed by the authors. In terms of the organisation of themes, this book consists of six parts. In Part I, Bowring shares his personal passion and conviction in outreach programmes as a geoscience professor from a leading research-intensive university, and explains, in his opinion, why geoscience outreach is important. Together with this chapter, it provides some relevant contextual background for the book.

Parts II, III and IV of this book focus on the links between geoscience research and schools/public outreach. The chapters in these parts show the main types of outreach activities in different areas of geoscience, and these field-, online- and workshop/laboratory-based outreach programmes underline the multidisciplinarity and interdisciplinarity of contemporary geoscience research. The rationale for presenting the diverse range of geoscience outreach programmes under these parts is to foreground the main approaches commonly adopted in outreach activities in geoscience. Note that some programmes involved adopting multiple approaches, in which case they are grouped according to the key approach featured.

Field-based activities are important to many geoscientists' research, and there is no better way to get students and others involved by having hands-on experience in the field. These activities are special to geoscience as a scientific discipline that often requires work outside a laboratory. Part II comprises three field-based contributions with fieldwork performed in very different physical environments. Yoshikawa et al.'s study of the permafrost and surface soil layers (Chapter 'Engaging Alaska Communities and Students in Cryospheric Research') shows how students and teachers in rural Alaska helped establish long-term monitoring sites. Novel use of manga and video series were featured alongside the fieldwork and educational activities in this project led by the Japanese professor. The impact of the outreach project on the communities in the remote regions is discussed. Westnedge and Dallimore describe their experience in a marine geoscience outreach programme in Canada (Chapter 'The Salish Sea Expedition: Walking the Gangplank of Science Outreach'), and they explain the importance of effective communication between scientists and the general public in their perspective chapter. Their project involved designing a map and guidebook as part of the marine expedition, putting geoscience research in the local contexts. In Chapter 'Problem-Based Learning in the Field Setting', Chan and Ho detail the integration of problem-based learning (PBL) in field-based education in Hong Kong. Their project involved the design and implementation of enquiry-based learning and teaching for high school students, and detailed evaluation on the pedagogical impact of this approach is also included. The authors demonstrate that the use of PBL in the field has the potential to be adopted widely in school curricula.

Online methods play an important part in education, and geoscience outreach is no exception. Part III consists of four chapters showing a variety of outreach programmes that were facilitated by the use of the Internet. In their perspective chapter (Chapter 'From Local to Extreme Environments (FLEXE): Connecting Students and Scientists in Online Forums'), Carlsen and his US-based colleagues discuss the use of online forums that helped link ocean scientists, teachers and students from around the globe. The authors highlight how the use of online forums allowed them to address various difficulties faced by research scientists in their outreach efforts. Barrett et al. explain the challenges with regard to the use of social media and the web in communicating scientific research (Chapter 'Communicating Scientific Research Through the Web and Social Media: Experience of the United Nations University with the Our World 2.0 Web Magazine'). Based at the United Nations University's headquarter in Tokyo, they share their experience with the development of an online magazine featuring environmental topics. In Dengg et al.'s chapter (Chapter 'Marine Geosciences from a Different Perspective: "Edutainment" Video Clips by Pupils and Scientists'), they showcase the production and hosting of YouTube-style online video clips on cutting-edge research topics in geoscience. This German project brought scientists, educators and students together to undertake this technically and scientifically challenging project. In Chapter 'Small, Subject-Oriented Educational Resource Gateways: What are Their Roles in Geoscience Education?', Cattadori et al. explain their development of an open-source online teaching resource in geoscience for school teachers in Italy. The project involved educators from a science museum, school teachers and research scientists in the construction of the information gateway.

Apart from field- and online-based outreach, workshops remain an important traditional approach in science outreach. There are four chapters in Part IV showing the range of possibilities with different scopes and scales of outreach activities that were based on workshops or laboratory experiments. Zollo et al. describe in Chapter 'The European Experience of Educational Seismology' their long-running school outreach programmes in seismology and detail their experience in Italy, France, the UK and Switzerland. The development of seismometers and the use of school-based monitoring stations are discussed. In addition, the authors propose that online-based activities will further enhance the communication between researchers, teachers, students and educators in their outreach programme. Bookhagen et al. discuss their US-based outreach programme involving principles and research in geochronology. The laboratory-based workshops for students and teachers are described in their chapter (Chapter 'EARTHTIME: Teaching Geochronology to High School Students in the US'), and both quantitative and qualitative evaluations were carried out for this school outreach project featuring challenging geoscience concepts. Čanić and Rasol showcase their workshop designed to raise awareness in meteorological principles and research findings in Chapter 'Little Meteorological Workshop: An Extracurricular School Activity for Pupils'. Their project was originally developed as a public outreach project in a science festival in Croatia, and is now incorporated as an extracurricular activity for primary school children and their teachers. In Chapter 'Grasping Deep Time with Scaled Space in Personal Environs', Jacobsen describes his Danish project that aimed to help develop a better understanding of the idea of geological time. His outreach project involved the use of physical installations on a university campus and in a science festival, as well as virtual installations on Google Earth and YouTube. His project clearly demonstrates the importance of using multiple methods in outreach activities.

Part V and VI of the book feature chapters showing how outreach activities associated with geoscience research may be enhanced. Chapters in Part V share a special focus on the importance of pedagogical considerations by taking a deeper look at the educational rationales behind the design of geoscience outreach programmes. These chapters highlight the significance of science education research in improving the theoretical rigour and quality of geoscience outreach activities. Last but not least, Part VI aims to provide ideas about how geoscience outreach programmes, on the whole, may be better supported and promoted.

In Chapter 'Integrating Geoscience Research in Primary and Secondary Education', Sparrow and her US- and Thailand-based co-authors discuss their programme on monitoring seasons through global learning communities, which was part of the International Polar Year project. Apart from the implementation, they show details of their comprehensive and detailed evaluations of their outreach programme. Barber shares her experience with the Canadian programme involving outreach on board a research icebreaker (Chapter 'Bridging Scientific Research and Science Education in High Schools Through Authentic and Simulated Science Experiences'). She explains the pedagogical rationales behind her project whose goal was to connect schools to climate change research. Details on the theoretical framework that underpinned the planning of the project are described. In Chapter 'Using Guided Inquiry Tools with Online Geosciences Data from the Great Lakes', Rutherford discusses her enquiry-based online outreach project. The chapter outlines the implementation of the outreach programme that featured online research and required students and teachers to formulate testable questions. The author invokes an extensive range of science education literature in her discussion.

There are two perspective chapters from the USA in Part VI. Rogers highlights the fundamental differences between how scientists present research findings and how the public understands research findings and explains how these differences often result in misunderstanding and miscommunication (Chapter 'Communicating Climate Science from a Data-Centered Perspective'). He advocates the use of observations based on scientific data as a good context for enhancing the communication between research scientists and the public. In Chapter 'Geoscience Outreach Education with the Local Community', Saltzman outlines her case for building on the strength of the institution and forging collaborations across the institution in geoscience outreach programmes. Her chapter focuses on her experience of designing and implementing outreach activities in a leading research-intensive university. She also shows the importance of being transparent in what can be expected of the researchers and educators in outreach programmes. The full chapter by King (Chapter 'Using Research to Promote Action in Earth Science Professional Development for Teachers') demonstrates the importance of supporting the professional development of Earth Science school teachers in the UK. He highlights the need for using research to enhance the professional development programmes and explains the reasons behind a successful programme, which is supported by an academia-industry partnership.

A diverse range of perspectives are featured in this book, including those from geoscience academics working in research-intensive and teaching-led institutions, science education researchers, educators, outreach programme directors from museums, public organisations and universities. There is a huge variety in the types of approaches used in their programmes, spanning different areas of geoscience research, and were implemented around the world. Despite these diversities, there is one unifying theme, which is loud and clear: outreach based on or enhanced by geoscience research is important and necessary. Underlying this belief are the passion and conviction behind those who want not only to convey geoscience research findings and their excitements to the outside world but also to share the vision that geoscience outreach should be implemented in effective and innovative ways. It is a multidisciplinary and interdisciplinary endeavour, as they unmistakably show.

Perceptions of Time Matter: The Importance of Geoscience Outreach

Samuel A. Bowring

Most people, at some time in their life, are faced with making decisions that would be better informed with basic knowledge of the interactions between the Earth's systems. This basic knowledge is critical for all people who must understand topics as diverse as the interactions between humans, their large animal symbionts, large-scale agriculture, and the Earth, including climate evolution; the availability of fresh water; issues of land use and development; preparing for natural disasters; and the supply of natural resources to support our current technological standard. Every student and adult, from grade school through university and beyond, should have a basic understanding of the ultimate complex system, the Earth. In addition, there are many opportunities to raise the awareness of the general public to the importance of geological processes at all time and length scales—from catastrophes to waste disposal to natural resource management to evolution. Increasing Earth Science literacy should be a major goal and crucial for the stewardship of the planet. All scientists should be responsible for reaching out, explaining what they do and why they think it is important in an accessible manner.

This book demonstrates that scientists and educators can teach a broad cross section of students about the Earth through diverse and innovative approaches, including field and laboratory exercises and the integration of research and education. As a geochronologist, my own philosophy of education is to make a deeper understanding of geological time central to all geoscience outreach that I do. Otherwise well-educated university students often have no concept of geological time, not because they believe in a young Earth, but because they have never been exposed to or thought about it. Time is central to any historical science from astrophysics to archeology, and I find that contrasting the timescales of post-industrial revolution monitoring of the planet to what we learn from much older records to be

S.A. Bowring (✉)
Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: sbowring@mit.edu

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a very useful exercise. Getting students involved using real data, including those collected as part of a class exercise, is essential at all levels. The simplest examples might include acquiring and interpreting data such as making temperature measurements taken at the same place and time every day to understand short- and long-term trends or monitoring and quantifying erosion of a nearby slope disturbed by human activities over a period of a few months. More complex problems could include mining and interpreting climate data of different precisions and accuracies over decades and centuries. Public policy related to sustainability and the environment should be based on data, and the world needs citizens with a basic understanding of how data are acquired, evaluated, and interpreted.

Crucial for understanding how we interact with the modern Earth and how we use Earth history to make predictions is an understanding of the timescales of geological processes. These include recurrence intervals of natural hazards such as volcanoes, earthquakes, and hurricanes, accumulation/formation/exploitation rates of fossil fuels and ore deposits, and the timescales of rapid shifts in climate from tens of thousands to hundreds of millions of years ago. Many tend to think of Earth history in terms of human timescales alone and do not always understand or comprehend the enormity of geological time. Our rapid exploitation of minerals and fossil fuels compared to the timescales for their formation should give everyone pause when we think about future generations. Integrating an understanding of time from the last century to the formation of our solar system is essential at all levels of education.

Forty to fifty percent of US citizens think that the age of the Earth is 10,000 years or younger. This is troubling when politicians and policy makers look at climate records for the past 10–50 years or less and use short-term (decadal or shorter) fluctuations in global temperature to evaluate whether or not humans have had a profound influence on climate. If climate records are extended back hundreds of thousands of years using ice cores and even millions of years using climate proxies preserved in the rock record, one can see fluctuations in greenhouse gases, global temperature, and their effects on biological evolution. However, using temporal constraints, we can calculate and compare rates of change and see that the post-industrial revolution changes in total greenhouse gas concentrations and temperature are alarmingly fast. A firm understanding of geological time and insights from the geologic record is essential for policy makers who make politically motivated decisions that can affect the quality of life of the entire planet for generations. Thus, it is imperative that we as scientists and educators do more to teach others about Earth history, deep time, and the fact that geological history can be used to better understand the impact of humans on the planet and to make predictions. In addition, we have much to learn from non-analogue or unpredictable events that may happen only once in the history of a planet. These include the oxygenation of Earth's atmosphere ca. 2.4 billion years ago, the apparently rapid diversification of animals ca. 540–525 million years ago, and the end-Permian extinction when, 252 million years ago, approximately 90 % of marine life went extinct.

It is puzzling that we find ourselves in this position, as young students are often indirectly fascinated with evolution by learning about dinosaurs as well as invertebrate fossils. Dinosaurs roamed the planet for at least 166 million years and went out with a bang 66 million years ago, making a nice contrast with the relatively short duration of human existence. It is imperative that we build on this natural attraction to include other deep time topics such as mass extinctions, global (Snowball) glaciations, the origin and rise of animals, and major perturbations to Earth's climate system. In fact, one could argue that for at least the last 580 million years, the environment has played a major role in evolutionary processes and the history of life. For example, most extinction events are linked to major changes in the environment and almost always involve climate perturbations. When we consider the changes humans have brought to the planet since the industrial revolution in the context of major events in deep time, we see that we have greatly perturbed the system.

A good example of a major climate event in deep time occurred approximately 56 million years ago, when CO_2 concentrations in the atmosphere were at least twice what they are today and global average temperatures were >5 °C warmer than today, an event referred to as the Paleocene–Eocene Thermal Maximum (PETM). The poles were ice-free and sea surface temperatures in Polar Regions were in excess of 20 °C. While an exact cause is still debated, the amount of CO_2 injected into the atmosphere over a period estimated at less than 10,000 years is comparable to the amount we will inject in a much shorter time period by consuming most of the known fossil fuels (approximately 4.5 trillion tons of carbon); rates matter!

The biological effects of the PETM were profound; deep-sea fauna suffered global extinction and some terrestrial mammals became extinct, while modern mammalian orders such as horses and primates first emerged. There were major migrations of mammals and a remarkable decrease in body mass. Mammals thrived by rapid evolutionary adaptation, although their total population was likely a small fraction of the seven billion humans we have today, not to mention large animals that live symbiotically with us (e.g., >20 billion chickens, ca. 1.5 billion cattle). Today, many humans have congregated in massive cities with complex infrastructure for distribution of food, medical care, and energy, requiring great expense to relocate. Thus, we are faced with a future that has the potential to be most unpleasant. Humans may survive most climate-induced change, but we could face massive reductions in population, destruction of much of our culture, relocation of large numbers of people due to sea level rise, and a drop in the standard of living even if we start contingency planning now. An appreciation of Earth history from the age of the Earth to the last millennium is essential for all humans to better understand what our future will be and how to plan for it.

A good teaching moment is to have students examine and plot temperature changes as a function of time, including estimates of temperature in deep time. Those who do not think humans have caused or are causing changes in global climate will often point to relatively short periods of time from, for example, last winter or summer being very cold or hot or show that temperature increases over the last 5 years are less than predicted by climate models as evidence for or against human agency. When students examine longer time periods the concept of signal vs. noise can be discussed, as can short- vs. long-term trends. While one can point to intervals in deep time when CO_2 levels and temperature changes have been dramatic, none have occurred at the *rate* we have seen since the industrial revolution.

The chapters in this volume provide exciting new approaches to teaching research-enhanced geoscience both within schools and to the public. Approaches include engaging people through field observations, using geoscience databases, and specially designed classroom and public outreach experiences on important topics that span climate evolution, seismology, and geologic time. I advocate making geological time a unifying theme for many of these topics from the timescales of observations to how the past may be used to inform the future. While many students think the Earth is 10,000 years old or younger, many others have just not thought about its age or how the age of the Earth is estimated. When asked how we know the age of the Earth, the response of many students and educated citizens is "carbon dating." While encouraging because a geochronometer is invoked, it exposes a lack of awareness of deep geological time and that ^{14}C dating is used for carbon-bearing materials that are ~50,000 years and less in age. However, this misconception can be used to segue into teaching about geochronology, half-lives, and choosing the right decay system for a problem. The discovery of radioactivity is barely 100 years old, and its application to determining the age of the Earth is without doubt one of the most remarkable accomplishments in the history of science.

Geochronology is the science of determining the ages of rocks and includes a variety of methods, from the decay of radioactive isotopes, to linking sedimentary rocks deposited in cycles to dynamical models of the solar system such as proposed by Milankovich, to using the pattern of reversals in the Earth's geomagnetic field. Geochronology can and should be taught as part of Science in primary, secondary, and postsecondary education, and it can be integrated into all aspects of teaching about the Earth system, especially using physics, chemistry, and biology. This can include rates of biological evolution and extinction from the past 100 years through to the rise of animals >580 million years ago, lifetimes of greenhouse gases in the atmosphere, temperature records over the past few 100 years, and the history of polar ice accumulations and climate over millions of years. At more advanced levels, integrating geochronology into other curricula might include demonstrating how measurement uncertainties influence our understanding of data. Involving active research groups in the educational process is a powerful way to provide role models and communicate the excitement of data gathering, interpretation, and hypothesis testing.

As part of the EARTHTIME initiative (www.earth-time.org), I led development of an outreach program on geochronology and how it can be used to develop a time line for Earth history (see Chapter "EARTHTIME: Teaching geochronology to high school students in the US" by Bookhagen et al.; this volume) with a hands-on approach. This program has been taught to junior high and high school students and covers basic physics of radioactive decay and how we actually date minerals to why we care about the ages of rocks and what caused major events in Earth history such as mass extinctions. Students enjoy the hands-on aspect and ask many questions related to everything from climate to the origin of the solar system. Many schools do not seem to have the time or resources to make this part of their formal curriculums although this program shows them it can easily be done. I consider it our responsibility as educators to ensure that preuniversity students are exposed to the concept of geological time and Earth history as context for our own existence.

Teaching geoscience necessarily involves the integration of biology, physics, chemistry, and math to better understand geologic processes. A good way to capture the attention of students of all ages is to use the latest data and controversies, “torn” from newspaper headlines and the latest journal articles. The instructors do not have to be active researchers in order to use data and ideas from the literature to stimulate their students. Time is central to geoscience and can be integrated in any discussion or lecture.

In summary, better science education from elementary school through adult learning is the only way to ensure stewardship of the planet for future generations. I advocate making geological time central to all geoscience outreach. Our planet’s future depends on fostering a deep appreciation for the short timescale humans have existed with what we know about evolution and climate evolution on timescales of millions to billions of years. Ultimately, the key is to think not just about change but rates of change—and when we do, we see just how fragile a place we inhabit.

Part II
Field-Based Approaches

Engaging Alaska Communities and Students in Cryospheric Research

Kenji Yoshikawa, Elena Sparrow, and Julia Stanilovskaya

1 Introduction

Permafrost is defined as ground materials that remain below 0 °C (32 °F) for 2 or more years. Permafrost forms when the ground cools enough in winter to produce a frozen layer that remains frozen throughout the following summer. The active layer (the soil near ground surface that thaws each summer) and the thickness of permafrost depend on local climatic conditions up to about 1,000 m thick, vegetation cover, soil type and moisture content, and any effects from the heat flow at the Earth's core.

The Permafrost/Active Layer Monitoring (PALM) Program is a research project that monitors the permafrost temperature of ground and the depth of the active layer in regions of permafrost and seasonal frost. Information learned from this research will help us understand the thermal state of permafrost and its effect on the natural environment and local ecosystems. Data recorded now will be the baseline for studies in the future, which makes this a long-term project. We hope to collect data for many years so that we can track how permafrost and the active layer change over time. To gather the data, we have established monitoring sites near communities throughout the permafrost and seasonal frost region in Alaska and other countries where ground is frozen. Students and teachers in the local

K. Yoshikawa (✉)
Water and Environmental Research Center,
University of Alaska Fairbanks, Fairbanks, AK, USA
e-mail: kyoshikawa@alaska.edu

E. Sparrow
International Arctic Research Center, University of Alaska Fairbanks,
Fairbanks, AK, USA

J. Stanilovskaya
Geocryology Laboratory, Sergeev Institute of Environmental Geoscience,
Russian Academy of Sciences (IEG RAS), Moscow, Russia

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schools participate in the program by reading measurements at the monitoring sites, recording data, comparing data online with other schools, and discussing what they learn. Classroom lessons on permafrost have been developed for students of all grade levels. The lessons, combined with activities at the measuring sites, offer students hands-on scientific experience and an opportunity to see the connection between science and research.

As part of this project, we developed a protocol for teachers around the world: GLOBE Seasons and Biomes Project. The GLOBE project will help to provide high-resolution spatial distribution of the thermal state of permafrost and will improve the general knowledge of Earth's climatic pattern; it also offers an opportunity for students to take part in understanding climatic systems. This project highlights the interaction between permafrost, the active layer, hydrology, and the climate system of the cryosphere, and provides a strong educational outreach program involving remote communities.

To ensure scientific integrity, all of the monitoring instruments have been installed by scientists, who select the sites representative of the surrounding biome and thermal conditions. The PALM Program is a unique opportunity for collaboration, in that it (1) uses scientifically accurate instruments, (2) is led and supervised by scientists who set up instrumentation and check data quality, (3) has a teacher/student-organized observation network, and (4) increases the spatial scale of monitoring sites that cover all the northern communities involved.

Most of the monitoring sites are located in remote communities, where the majority of residents depend on a subsistence lifestyle. Changes in climate, length of seasons, and permafrost conditions directly affect natural resources and subsistence activities. Changes in permafrost conditions affect local ecosystems and hydrological regimes and can influence the severity of natural disasters.

In addition to extending our knowledge of the environment of the cryosphere, the program involves school-age students. Several students have been using data from this research for their school projects and have been inspired to continue their studies. Data gathered from these stations are shared with other schools and made available to the public through the program's website (http://www.uaf.edu/permafrost). Increasingly, communities are becoming interested in this project, not only for its educational benefits but also for its implications for disasters such as mudslides, loss of food-storage capability in frozen ground, and water pipes bursting from ground freezing at lower depths. Challenges in education outreach include the high cost (dollars and time) of reaching remote study sites scattered all over the vast Alaska landscape and designing instructional materials that help students understand the science concepts behind the long-term study of permafrost and the active layer. In addition to scientific measurement protocols and learning activity development, a superhero—TunnelMan—has been created for instructional purposes. TunnelMan's adventures have been produced and made available on videos, the project's website, and YouTube. Through this project, students in remote communities learn science in a way that is meaningful to their daily lives. In addition, they experience research participation within a larger scientific community, expanding their worldview.

2 Motivation and Rationale of the Project

2.1 Scientific Viewpoint

Permafrost regions occupy about one-quarter of Earth's land surface. Permafrost is one of the most important components of the terrestrial system of the cryosphere, and this physical element of the landscape is one of the most sensitive to climatic change. Therefore, observing the interactions between permafrost and other components of the system of these regions (the climate, hydrology, biogeochemistry, vegetation), especially during a period of possible climatic warming, is among the most important aspects of cryosphere research. The changing properties of permafrost play an important role in driving the ecosystem balance and affect carbon and water cycles (Oechel et al. 2000). Additionally, structures built on or near ice-rich permafrost can suffer severe damage from thaw-induced ground settling, which will accelerate if mean annual temperatures continue to rise (Osterkamp et al. 2000; Romanovsky and Osterkamp 2001). Within the sensitive permafrost region, the discontinuous permafrost zone is the most likely to respond to climatic warming. Most rural communities in Alaska are located in this zone. Throughout the circumpolar North, boreal forest widely overlaps the area of discontinuous permafrost (Péwé 1975). Thermal conditions of discontinuous permafrost are quite unstable, as the ground is close to thawing, with temperatures often hovering at −1 °C or warmer.

Table 1 is an overview of the principal permafrost monitoring programs in the circumpolar North, with major findings and results summarized. Most notable is the evidence of a warming trend, even with few permafrost monitoring sites.

3 Implementation and Timeline

3.1 Approach

The majority of Alaska communities included in this project are located in remote areas, without road access. Air transportation is typically used to reach these communities, but this mode of travel was not ideal at the beginning of the program when equipment was needed to establish each monitoring station. To establish a monitoring station, a borehole, casing pipes, and drill equipment are needed. This technical part of establishing a station presented some difficulties. Each monitoring station requires the drilling of a 3–6 m deep borehole for measuring ground temperatures and a 1 and 5 m deep borehole for monitoring the seasonal/active layer. The remote location of most villages created the necessity, and therefore a great opportunity, for developing a portable, lightweight, small-diameter drill system. Such a portable

Table 1 Recent trends in permafrost temperatures measured at different locations (Romanovsky et al. 2002)

Country	Region	Permafrost temperature trends	References
USA	Trans-Alaska pipeline route (20 m), 1983–2000	+0.6 to +1.5 °C	Romanovsky and Osterkamp (2001)
	Barrow Permafrost Observatory (15 m), 1950–2001	+1 °C	Our ongoing research
Russia	East Siberia (1.6–3.2 m), 1960–1992	+0.03 °C/year	Our ongoing research
	North of West Siberia (10 m), 1980–1990	+0.3 to +0.7 °C	Pavlov (1994)
	European North of Russia, continuous permafrost zone (6 m), 1973–1992	+1.6 to +2.8 °C	Pavlov (1994)
Canada	Northern Mackenzie basin (28 m), 1990–2000	+0.1 °C/year	GSC data
	Central Mackenzie basin (15 m), 1985–2000	+0.03 °C/year	GSC data
	Alert (15 m), 1995–2000	+0.15 °C/year	Geological Survey of Canada (GSC) data

drill system is strongly affected by the grain size of frozen materials, which was problematic since permafrost conditions and local geology vary greatly among the different locations. Though a design for augers and coring bits (mechanical properties) for fine-grained frozen soils had already been well developed, drilling in frozen gravel, boulders, and glacial sediments is extremely difficult, even when using heavier track-mounted hydraulic drill systems, and required a different drill system. We developed a method of drilling through frozen gravel using a portable drill system. More than 250 monitoring sites have been established.

For the most part, we used snowmobiles to reach remote locations during spring months. Snowmobile travel took place in the spring of 2007, 2008, 2009 and 2013. We visited 93 communities, traveling 12,000 km (7,500 miles) to set up monitoring sites. We used trails between communities—winter trails, dog-mushing trails, the Iditarod trail, and the Iron Dog trail—but not always. Most of the time we had to break trail. In the forest, snow was deep and it was difficult to make trails because of trees, but on the tundra, hardpacked trails made travel easier. This snowmobile-travel campaign was greatly successful, both logistically and socially. Most rural communities in Alaska and Canada are not visited by scientists, and when it occurs, visitors usually arrive and depart by airplane. Snowmobiles are an important means of transportation in remote areas and people find them interesting, especially teenagers and other school-age kids. We arrived on new snowmobiles from far away, having driven great distances. That had a strong impact on local people and got the program off to a good start. In 2011, we visited southeast Alaska communities by small boat to establish monitoring stations. We traveled the Inside Passage (fjords) to reach these 23 communities. Arriving by boat had a similar impact as arriving by snowmobile.

After a monitoring station is established, we visit communities again, traveling by snowmobile, boat, or airplane. It is important to revisit schools and maintain the strong connection with students and communities. Presently, almost all Alaska communities are in the PALM Program network, which is not only important for filling the scientific data gap but also important for furthering good relationships with teachers. Many rural schools experience high teacher turnover. Usually, however, our teacher connection remains in the PALM Program network if the teacher stays in Alaska. Throughout the year, we maintain regular communication and provide ongoing follow-up support with teachers at all schools near the permafrost monitoring stations that we have installed. We send out newsletters via e-mail monthly and correspond by e-mail or speak by phone with teachers daily. We also maintain a blog (updated almost daily) and a Twitter site on the PALM Program website.

3.2 Classroom Activities and Lessons

The classroom activities developed for the Permafrost/Active Layer Monitoring Program are differentiated by age group. Multi-age classrooms, in which older and younger students work together on science and math subjects, are common in rural Alaska. In many rural Alaska districts, students of all ages must pass "End of Level Tests of Attainment" before moving on to instruction in more advanced scientific concepts.

For this reason, a "spiraling" method was used to develop the permafrost curriculum, introducing advanced concepts in small doses for early levels and then building them in complexity for higher levels. Progressive levels of instruction concerning permafrost geophysics and related use of remote sensing start with basic principles and concepts (Levels I and II), build to earth processes and cycles of geomorphology (Levels III and IV), and conclude with atmosphere–ocean–land interactions, feedbacks, and energy transfer (Levels V and VI). Levels I and II correspond to grade equivalent K–4, Levels III and IV to grade equivalent 5–8, and Levels V and VI to grade equivalent 9–12.

Classroom lessons provide the framework for offering instruction. Online lectures, multimedia activities, "TunnelMan" videos, and online comic strip booklets are designed to give teachers instructing multi-age classrooms the flexibility to supplement classroom lessons when needed. The online scientist mentorship is designed specifically for teachers in geographically isolated rural villages in Alaska. Through online scientist mentorship, teachers have their questions answered and rural teachers are supplied with auxiliary resources (designed within and outside of the PALM Program) that augment permafrost instruction.

The program (1) offers teachers unique opportunities to integrate research and education by providing students a chance to work with and learn from experienced permafrost scientists; (2) provides classroom lessons on permafrost and the active layer, an important part of Alaska geosciences; and (3) distributes by DVD and

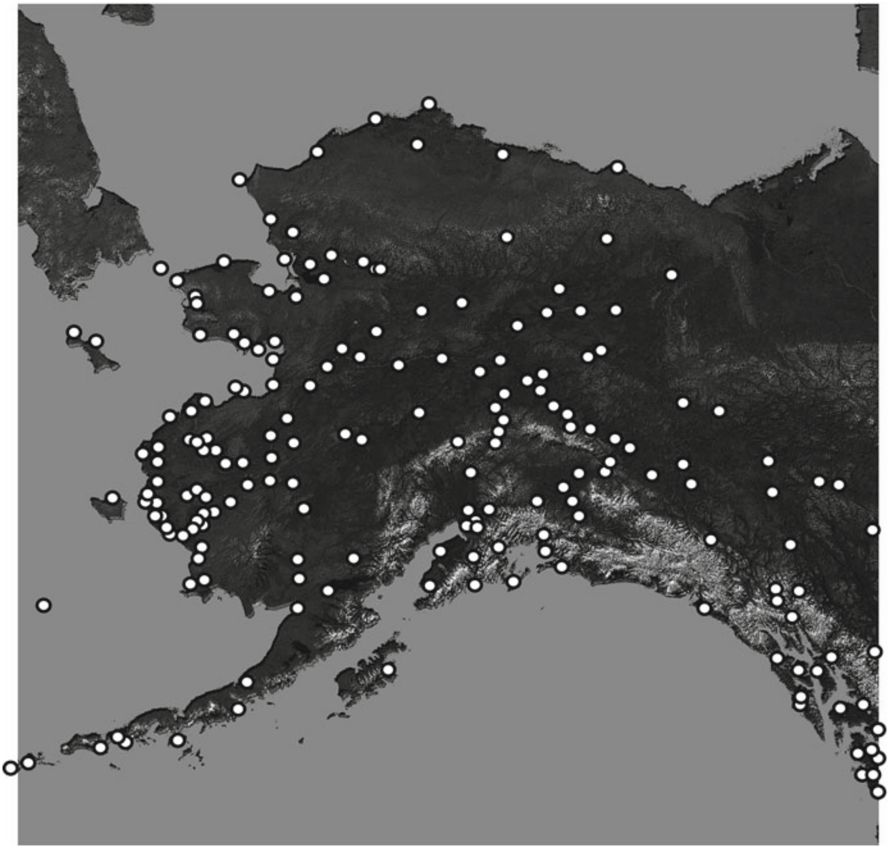

Fig. 1 Permafrost monitoring sites

through Internet an entertaining educational movie series called "TunnelMan." Educational activities include the following:

1. To help students understand permafrost and its impact on the environment, permafrost monitoring sites are established and boreholes are drilled. Scientists introduce the project and guide student discussion, focusing on the question, "Why do we need to monitor permafrost?" (Fig. 1)
2. To demonstrate scientific methodology, design, and fieldwork, frost tubes are installed, data loggers are set up, and scientists calibrate temperature sensors with assistance from students. Students and teachers explore the following questions with scientists' guidance: "What kind of sensors and instruments are we using?" and "How do these instruments work for us?" We provide teachers with a set of classroom lessons (Figs. 2 and 3).
3. About a year after monitoring stations are established, during the scientists' return visit to the communities, a second set of lessons to explore the temperature

Fig. 2 Students watch borehole installation (*left*) and experience communicating with the data logger via laptop computer (*right*)

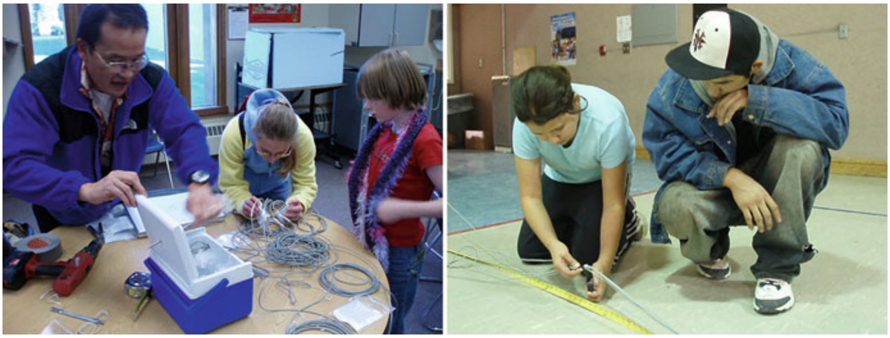

Fig. 3 Students prepare ice bath for calibration process (*left*) and set up sensor length for different depths (*right*)

data is developed in partnership with the teachers. After 1 year of data collection, students use the data to investigate permafrost and frozen ground, climate change impact on permafrost stability, and methods of monitoring changes in permafrost. Teachers download the data and use an MS Excel spreadsheet to plot monthly profiles, calculate the average temperature for each depth, and estimate active layer thickness. At this point, students focus on the following questions: "What is going on in our village?" "What will most likely happen in the future in our village?"

4. A model predicting changes in local permafrost is developed and used by students in the classroom. Students share data, comparing their data with that from different monitoring sites all over the world. Our hope is that by this point, students will understand many of the issues related to permafrost and related effects on the world around them. Teachers supplement the curriculum with an entertaining and instructional movie, "TunnelMan" (Figs. 4 and 5).
5. For students in the upper grades and for national park visitors, more-advanced classroom lectures/demonstrations are available, which offer opportunities for

Fig. 4 Demonstrating to students the seasonal variations of ground temperature using obtained data

Fig. 5 Students measure active layer depth (*left*) and look at physical details of frozen soil composition (*right*)

deeper and more complex understanding of the interactions between permafrost and climate change. One example of the effects of natural phenomena is the impact of forest (or tundra) fires on permafrost. Fire has a strong impact on permafrost degradation; fires burn away the insulation layer, which changes the thermal condition of the permafrost. Students measure and simulate the impact that wildfires of varying severity have on permafrost.

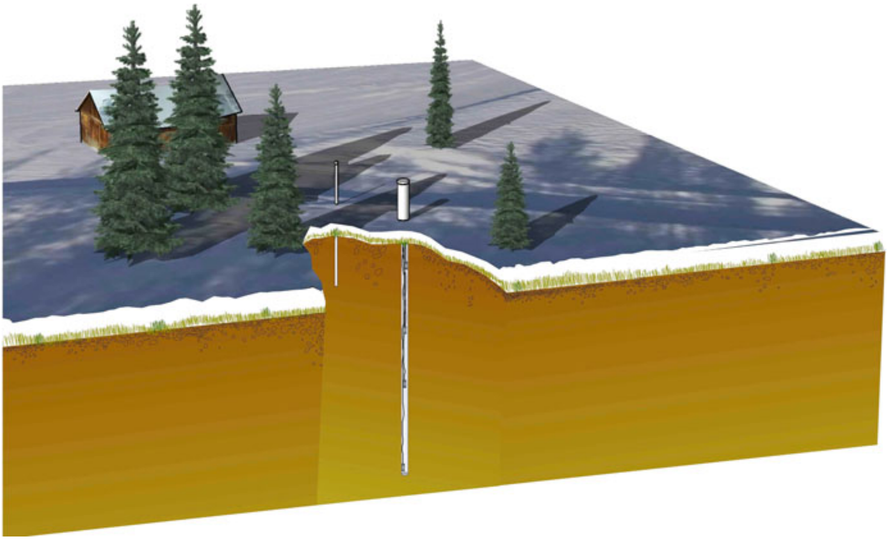

Fig. 6 Temperature monitoring station and frost tube

For maintenance purposes and educational outreach, the majority of our monitoring sites are located at or near schools or national park headquarters. This arrangement allows easier accessibility to equipment, provides educational opportunities by involving students and teachers in research, and facilitates data collection. A map of Alaska shows the locations of the communities (Fig. 1). Figure 6 shows a diagram of installed instruments. Permafrost temperatures are shown for three communities in Fig. 7. The trumpet curve (named for its shape) in these graphs are determined by soil temperature points at certain depths during a year. The ground temperature variations show seasonal changes near ground surface.

The profile in Fig. 7a (Wainwright) shows typical seasonal variation for soil temperature in a northern part of Alaska. Zero annual amplitude permafrost temperature is about −7 °C at 10 m below ground surface. Permafrost is colder and stable, with a shallow active layer (less than 1 m). Figure 7b shows a unique profile near the mouth of the Yukon River (Emmonak). Permafrost is presently 14 m thick, and it is possible that warm Yukon River groundwater flows underneath it, creating a strong gradient in soil temperature. Figure 7c shows a typical soil profile in Interior Alaska. This graph of soil temperature at Pearl Creek Elementary School in Fairbanks shows that the depth of no seasonal change is 2.5 m (8 ft) below ground surface. The depth is much shallower here because the temperature is close to the thawing point with almost no trend (straight up profiles). The reason for the shallow amplitude is due to heat transferred by phase change (latent heat transfer). The summer line in the Fairbanks graph shows that ground surface is above freezing, but at only 1 m (3 ft) below ground surface, the line crosses the 0 °C (32 °F) point. Beneath this point, soil is frozen. Most of the year, the upper layer is frozen too, but this layer thaws

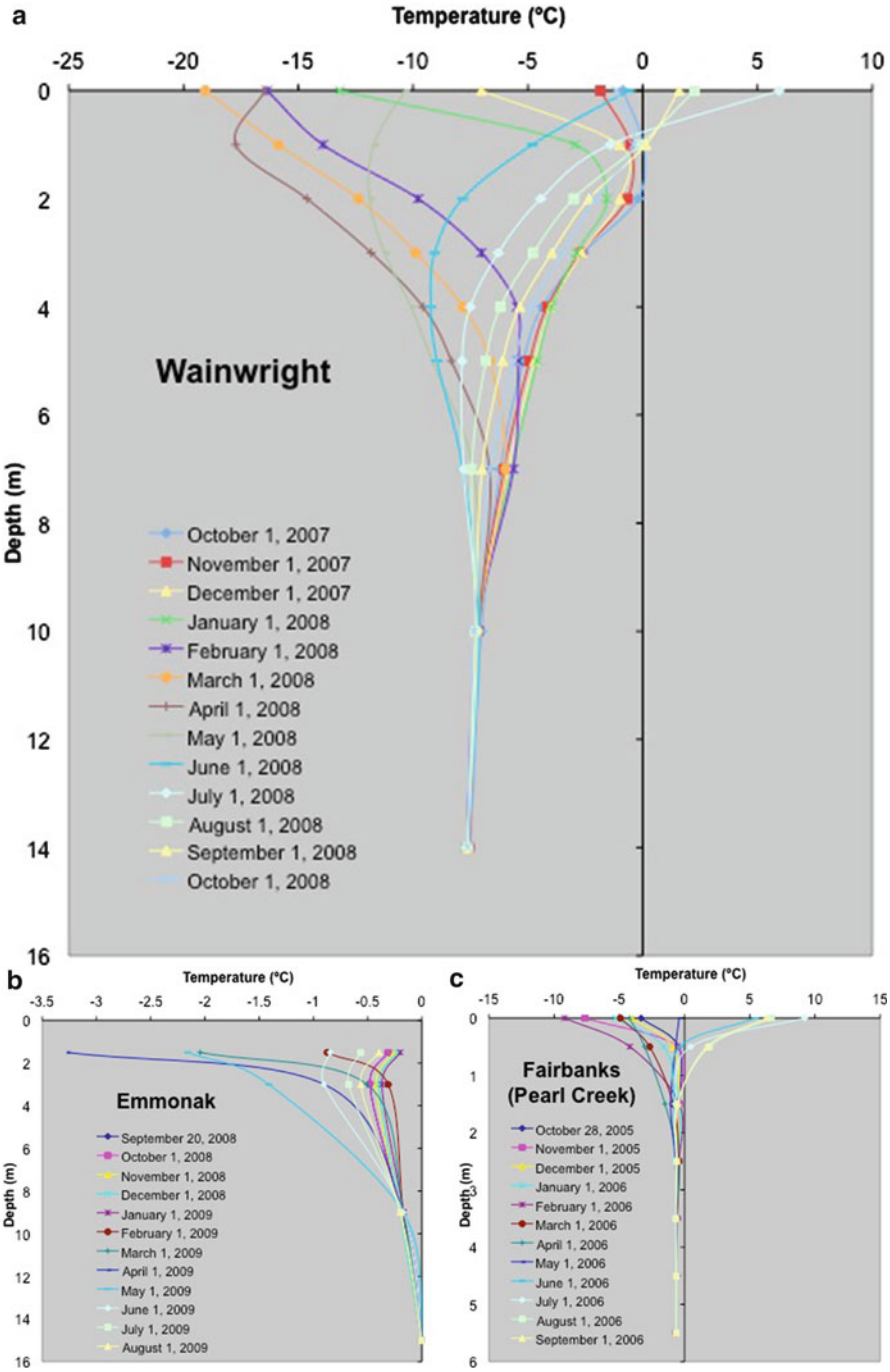

Fig. 7 Examples of permafrost temperature profiles from villages (**a**) Wainwright, (**b**) Emmonak, (**c**) Fairbanks

Fig. 8 Screenshot from TunnelMan Episode 1

each summer (the active layer). The main mechanism of ground temperature change is conduction. It takes time for heat to penetrate the ground. Deeper ground does not respond as quickly as ground surface. In the middle of winter (February), the ground surface is very cold, but the cold has not reached deeper underground yet. April is the coldest time of year 1 m (3 ft) below ground. Usually by then, there are lots of sunshine and half the snow has melted. It is possibly the most beautiful time in Alaska. Only 1 m below ground, however, it is the coldest time of the year, and pipes may freeze unless they are heated.

3.3 Video as Instruction Activity: TunnelMan Series

For public lectures and classroom instruction, classical methods of presentations (e.g., using PowerPoint) work well, but the video series "TunnelMan" has proven to be one of the most effective teaching tools for students (Fig. 8). This video series appeals to students in general, but it is especially successful at holding the attention of students who have attention-deficit challenges. TunnelMan, our underground superhero, helps explain permafrost and the soil temperature monitoring program in a movie, each lasting 4–6 min. The educational viewpoints of each episode are discussed after the video is shown. An important point here is that, presently, most villages in Alaska have no radio or television stations, but they do have Internet access. Most students have an iPod type of music/video device. These environments are excellent for teaching, as young people are looking for cool video or music entertainment.

Many teachers working with the program's curricula, such as Mr. Robert Stagg from the Aquarian Charter School in the Anchorage School District and Ms. Carol Cologie from Crawford Elementary in the Fairbanks North Star Borough School District, use "TunnelMan" videos in their classrooms. Opinions of the "TunnelMan" series as a teaching tool have been encouraging. Comments include, from Stagg, "Tunnel Man is the best! I think that if I had to model my teaching after anyone it would be after Kenji!" and from Cologie, "Kenji Yoshikawa's permafrost tunnel tour, and his video of TunnelMan—that's the way I like to teach! You know, I like to model what Kenji does, teaching through humor and making things real."

According to Mr. Bill Streever of the *Alaska Dispatch*, who reviewed teacher comment sheets in preparation for a news article, the following comment from an unnamed teacher in a rural Alaska village is typical: "December 2nd the frost tube read 34 and the snow depth was 40 cm. The grade 8 students can't wait until it's their turn to go out and take the measurements, even when it's very cold outside."

In the *Alaska Dispatch* article, Streever concludes:

> And here is another key point that both Professor Kenji Yoshikawa and TunnelMan bring to the villages: Village kids matter. A scientist from Japan thinks village kids matter enough to justify 3,500 miles by snow machine. Whether or not they become scientists, students know this: A Japanese man came on a snowmachine with a message of enthusiasm and a hands-on approach to life and left behind a permafrost observatory and, even more importantly, a sense that what happens right here matters, that this isolated village is not alone in a warming world.

3.3.1 TunnelMan Episode 1: Ice on Permafrost

This first episode of TunnelMan is a story, a process-type movie. After TunnelMan emerges from an ancient permafrost tunnel, he explains about ice (ice wedges) in frozen ground. Animation and music (Alicia Keys' "No One") are important aspects. In 2008, this song was popular among teenage students and its lyrics help with explanation. At the same time, educationally, we are concerned with thawing of ice-rich permafrost. Dry permafrost or frozen bedrock also exists in Alaska, but they are not of concern since their thawing would not undermine structures. Almost all infrastructure damage from thawing ice-rich permafrost is due to inadequate building design for the conditions. At the kickoff of this series in 2008, the video worked great in all of the communities and in university permafrost classes including in Russia, Germany, Japan, Spain, Argentina, England, and Norway. It seemed, though, that this movie was not cool enough for boys (mainly high school senior students) and was hard to watch repeatedly.

3.3.2 TunnelMan Episode 2: Hop-Pop TunnelMan

After releasing Episode 1, we tried to focus on including the favorite music of teenagers and making the videos captivating enough to watch repeatedly. The topic of Episode 2 is permafrost monitoring, that is why it is important to monitor temperature. We chose music with a rap beat and changed images and topics faster for students who might not understand the contents at a single viewing. We created original tunes with a rap beat and scientific lyrics. Screen shots are ten times longer than in Episode 1, but are compressed into 4 min of show time. Some of the words are slang that is not generally used in classroom instruction, which could be a problem in certain schools or with elementary-age students. Using slang was successful for catching the attention of most teenage students. Some students even downloaded and installed this episode on their own device.

3.3.3 TunnelMan Episode 3: Active Layer Monitoring

Episode 3 is probably the favorite of teachers, though not of students, because of the song "Volare" by the Gipsy Kings, popular in the late 1980s, the teacher's generation. The contents of this episode are classic, more like a typical educational video: how to install the monitoring equipment, what can be observed, the importance of the frost tube, etc. This is an instructional video that aids the teacher somewhat. Since there are many educational videos online today, we felt that this approach was not exactly our aim. However, the episode served well in teaching about frost tubes and other equipment, all explained within 3 min.

3.3.4 TunnelMan Episode 4: Geomorphology

Episode 4 music returns to rap beat and combines a classical movie idea (*Wizard of Oz*). This combination seems to appeal to all generations, even with the switch to rap beat. The purpose of this video is to help viewers understand permafrost and cold region landforms, especially those landforms near the students' communities. After watching Episode 4, some students have developed an interest in flying over their village to see the landforms, which means that part of the production has been successful. Still, we feel that using a different media or class lesson to increase their knowledge of periglacial geomorphology and landscapes is beneficial.

3.3.5 TunnelMan Episode 5: Permafrost and Climate Chronology

Episode 5 is the last episode in the TunnelMan series and released in June 2012. This episode explains the last 140,000 years of Earth's climate and permafrost history. Key goals of this video are to help students understand that climate is always changing (never stays the same) and that most of the permafrost in Alaska was established during the last glaciation (e.g., that thawing occurred during the last inter-glaciations). During the last glaciation, humans migrated across Beringia from Asia, becoming the ancestors of Alaska Natives. Filming for this episode was done at Africa's Rift Valley (the cradle of humankind), Western China, the Peruvian Andes, and several Alaska locations.

We also developed several videos related to our program: "−40 °C World," "Ice Fog," "Snowmobile Trips in This Program," "Boat Trips for Southeast Alaska," "Mongolian Borehole Hunting," "Peruvian Andes Permafrost Drilling," and "Kilimanjaro Trip." Our Kilimanjaro permafrost expedition was a successful trip that included total four science teachers and four students from Alaska. We traveled in 2010, 2012 to the summit of Kilimanjaro. More than 700 questions arrived by e-mail during this expedition from 95 countries. Our fellow travelers, the students and teachers from Alaska, were helping to answer all questions during the ascent of the mountain.

3.4 Manga: TunnelMan Cartoon

The Japanese cartoon, Manga, is becoming popular in the USA, including the rural communities of Alaska. This cartoon idea presents a great media opportunity for Alaska Native students. We developed "TunnelMan Return in 2058," a 32-page Manga story (Fig. 9a, b). This story takes place in Alaska in year 2058 (following International Polar Year). People are looking for proof of climate change, likely in temperature. Our 50-year-old vintage instrument, installed in 2008, helps the world to understand world climate. We hope this message underscores the importance of the program's work and helps us avoid vandalism of existing monitoring stations. All of the contents of our work are available on http://www.uaf.edu/permafrost.

3.5 Active Layer Monitoring

Unlike permafrost monitoring, the frost tube program is much more dynamic and active to students. A frost tube is an instrument that measures when and how deeply soil freezes. Frost tubes are made of three tubes that fit inside each other. The innermost tube is marked every 5 cm and filled with colored water; it fits inside a radiant heat tube (sealed on the bottom), which fits inside a PVC pipe, open on both ends (Figs. 10 and 11). The innermost tube of the frost tube is about 12 mm in diameter. When inserted in the hole drilled in the ground (with a drill hole), the frost tube's underground end reaches to the deepest level of frost or to the permafrost layer. The aboveground end (about 1 m long) is capped to prevent air temperature from influencing the underground temperature reading and to keep snow and water out. The innermost tube with colored water shows where ice has formed underground. We lift this tube out from the two outer tubes and note at what depth the ice has formed. It is easy to see the boundary between ice and unfrozen water, because the ice looks clear and the water looks colored. During frost heaves, only the outermost tube is affected. Students can monitor the timing and depth of freezing in soil at a frost tube site.

Students measure the depth at which water in the frost tube has frozen once a week, to get an indication of when the surrounding soil has also frozen. Our large network of sites provides greater comparison of timing and depth of freezing in soils in different regions around Alaska and the world (Fig. 12). Working with

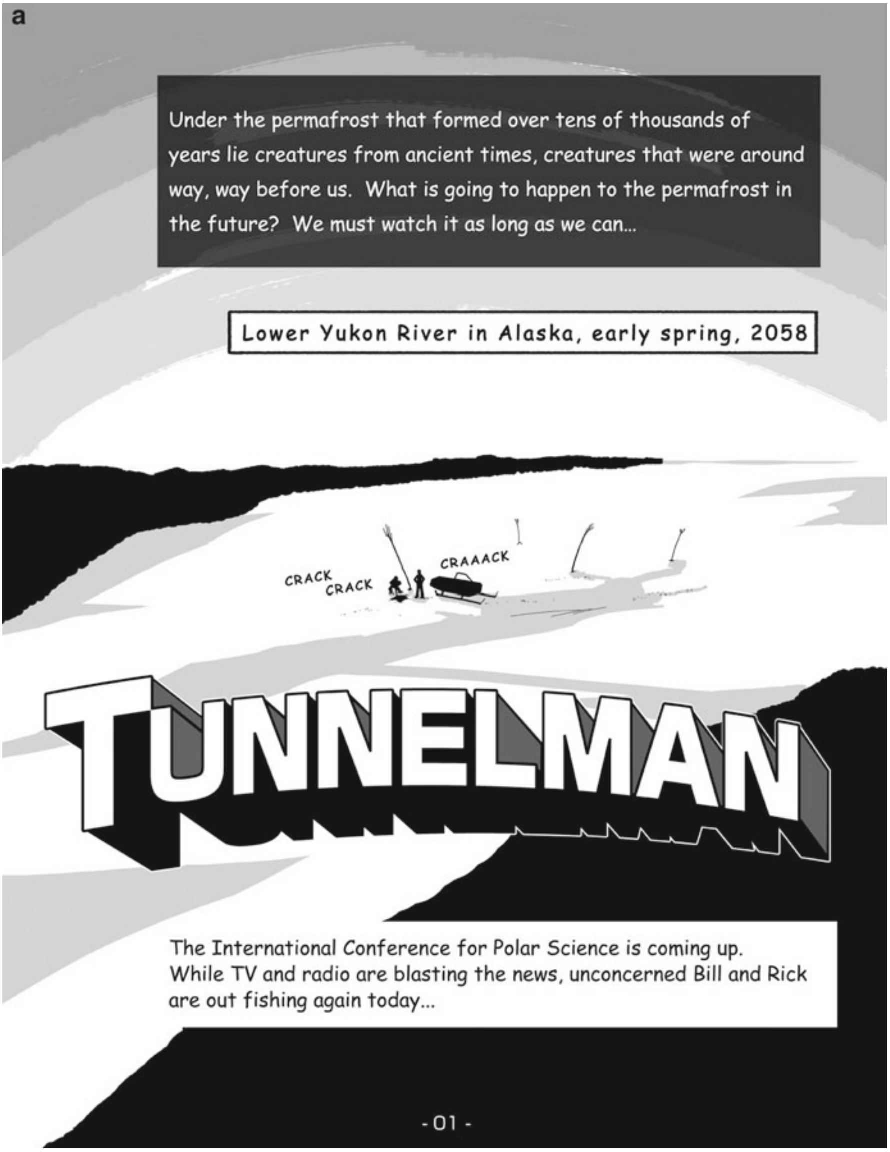

Fig. 9a Front (cover) page of our Manga (Japanese Cartoon) from TunnelMan Returns

temperature data, advanced students can predict the timing and depth of freezing for upcoming seasons or in a future scenario following climate change. The presence or absence of frozen ground has a strong effect on hydrology. Frozen soil acting as an impermeable layer affects water availability to root systems of plants and the recharge of groundwater reservoirs. A more-detailed description of the GLOBE frost tube protocol is found at GLOBE (2011).

b

Fig. 9b This story takes place in Alaska in year 2058 (following International Polar Year). People are looking for proof of climate change, likely our temperature monitoring network will be useful at the time

The frost tube program has been a great success in northern communities, because it is relatively easy to install, is cost efficient, and is a highly dynamic student activity. We installed a small one-channel data logger connected to an air temperature sensor next to the frost tube. From the surface temperature data, freezing degree days (freezing index) and thawing degree days (thawing index) as well as mean

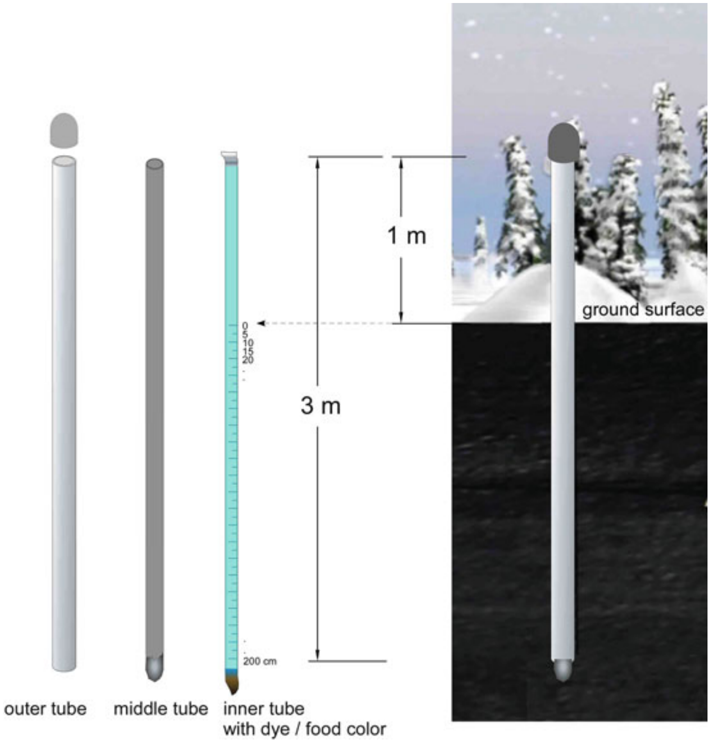

Fig. 10 Components of a frost tube

annual temperature can be calculated (Fig. 13). Examples of data collected are given in Fig. 14. These data could be used in a simple formula for predicting depth of freezing in the future.

4 Some Outcomes of This Project

4.1 Permafrost Failure Impacts Rural Communities

The discontinuous permafrost region in Northwestern America is particularly sensitive to climatic change. Intense summer rain or extreme summer drying can accelerate rates of thermal erosion by changing the surface conditions in areas of ice-rich permafrost. The part of Yukon, Canada, and northwestern Alaska, both of which were covered by glaciers during the Last Glacial Maximum (LGM), are widely recognized as one of the most ice-rich (buried glacier ice in permafrost) and thaw-sensitive areas in the world. In particular, glaciated areas are prone to develop retrogressive thaw slumps from the thawing of buried glacial ice bodies. The volume of

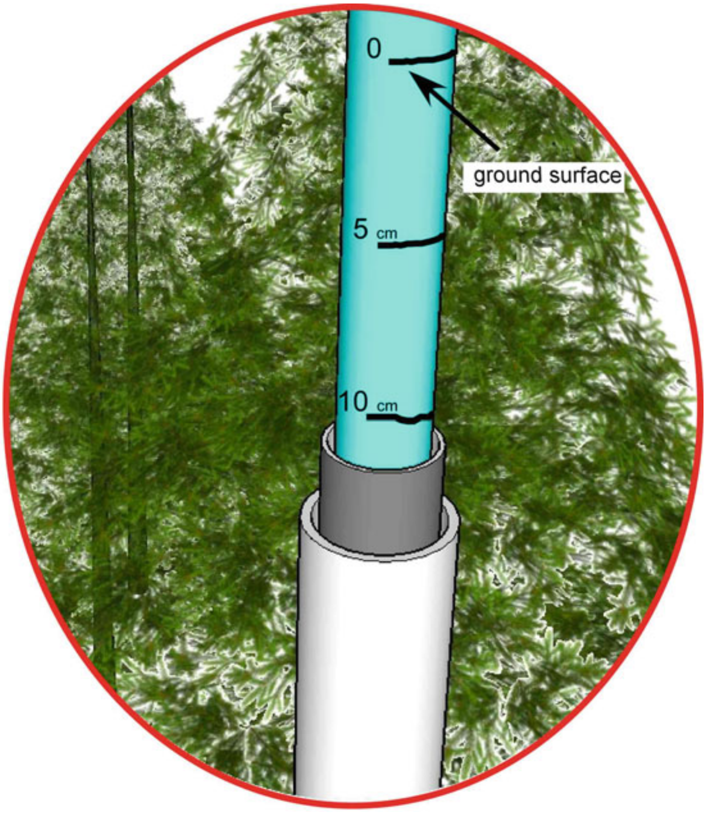

Fig. 11 Another view of the frost tube showing inner, middle, and outer tubes

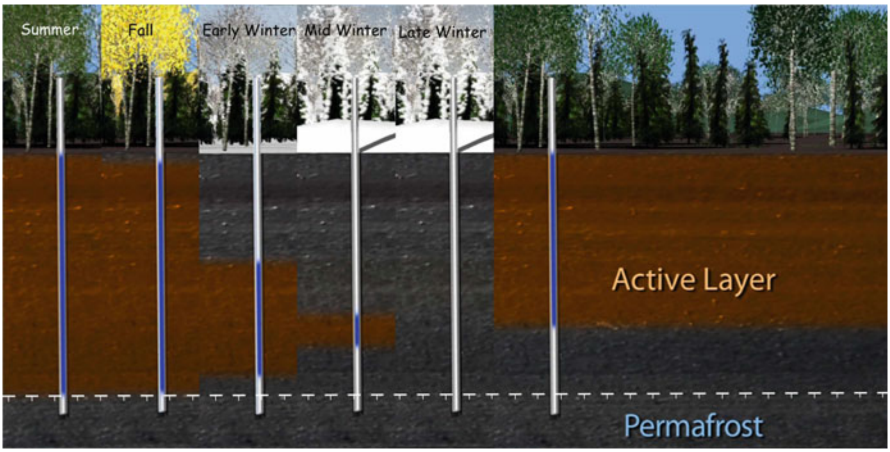

Fig. 12 Progression of freezing

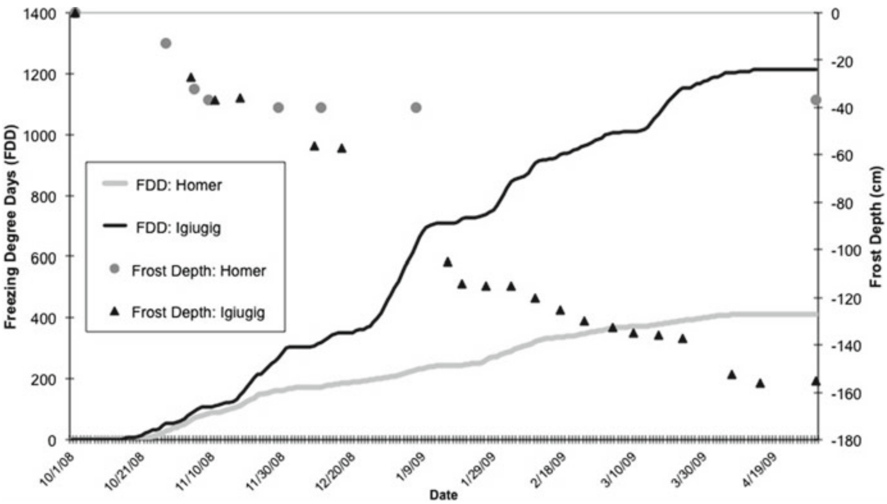

Fig. 13 Examples for freezing degree days and frost depths at Homer and Igiugig, Alaska

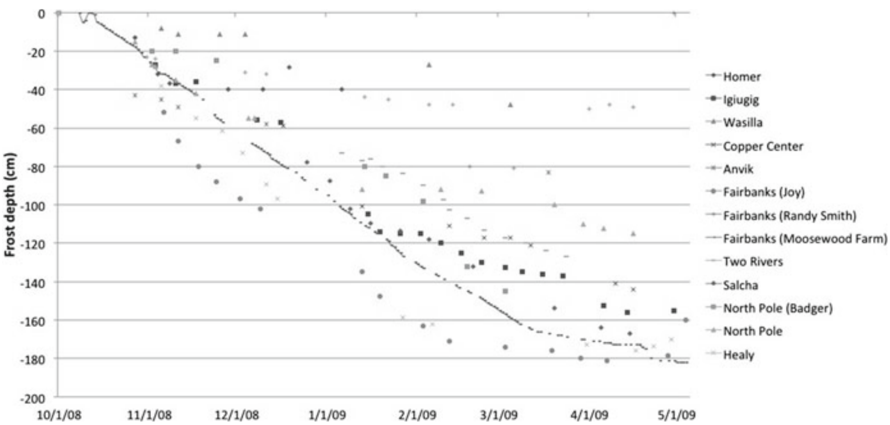

Fig. 14 Examples of frost tube measurements in rural communities, Alaska

sediment and ground ice eroded by retrogressive thaw slump activity has discharged large amounts of suspended sediments into marine or river systems (Fig. 15). Large quantities of suspended sediments have impacted drinking water sources for rural communities and may jeopardize critical fish-spawning habitat.

In 2004, a huge retrogressive thaw slump occurred at the upper stream of the Selawik River in Alaska. White fish is a major source of protein for those who live in the village of Selawik, and residents are concerned about the white fish resource. Since the ground failure in 2004, the village mayor, school principal, science teacher, and students have supported the PALM Program by sampling

Fig. 15 Retrogressive thaw slump near village of Selawik

suspended solid measurements. A similar problem occurred in 2005 at Kivalina, another village in Alaska. High, concentrated, suspended sediments are entering the intake of the village's drinking water system. Village water is drawn from the mouth of Wulik River, where several retrogressive thaw slumps have

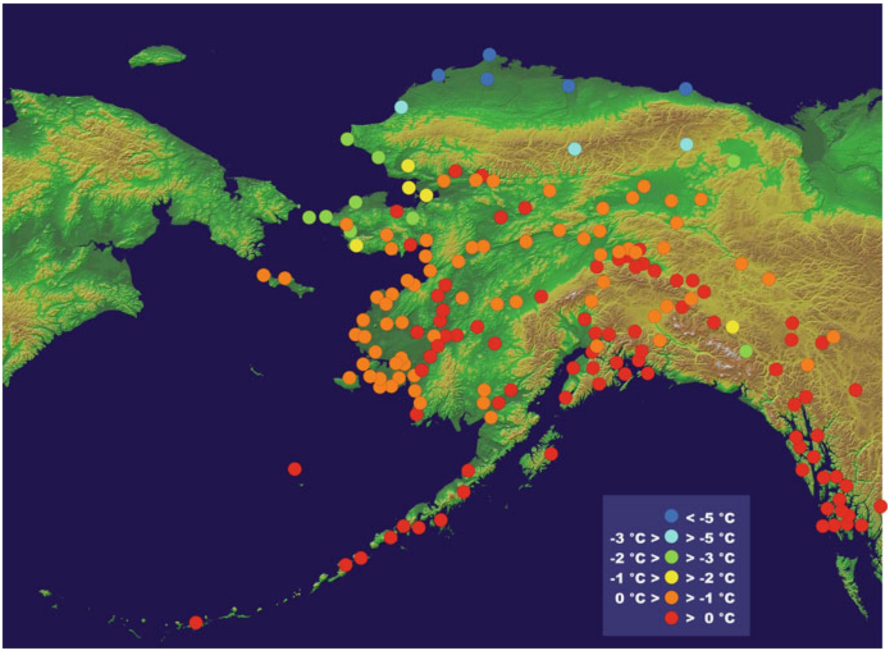

Fig. 16 Map of our monitoring network and the results from ground temperature distributions

occurred upstream. In general, permafrost-related hazards add to the interest in the PALM Program, and our program provided important information to the communities (Fig. 16).

4.2 Ice Cellar (Sigluaqs)

An ice cellar (called a *sigluaq*) is one of the smartest ideas of northern Natives. Mainly whaling communities have one or several ice cellars in the village. The meat stores well in this traditional natural freezer that makes use of permafrost; however, ice cellar temperature depends on permafrost temperature and climate. We monitored ice cellar/permafrost temperature with whaling captains and students of whaling villages such as Gambell, Savoonga, Little Diomede, Wales, Kivalina, Pt. Hope, Pt. Lay, Wainwright, Barrow, Nuiqsut, and Kaktovik. Reference measurements from Canada and Russia were employed. Most cellars are located 3–6 m below ground surface. That depth is still within the temperature seasonal fluctuation zone, which is usually −3 to −13 °C at cellars in Barrow (Fig. 17a). Climatic change has been suspected of compromising and causing damage to ice cellars in northern communities, with thaw and spoilage of meat a potential problem. Investigation of temperature regimes in these cellars is critically important for the continued well-being

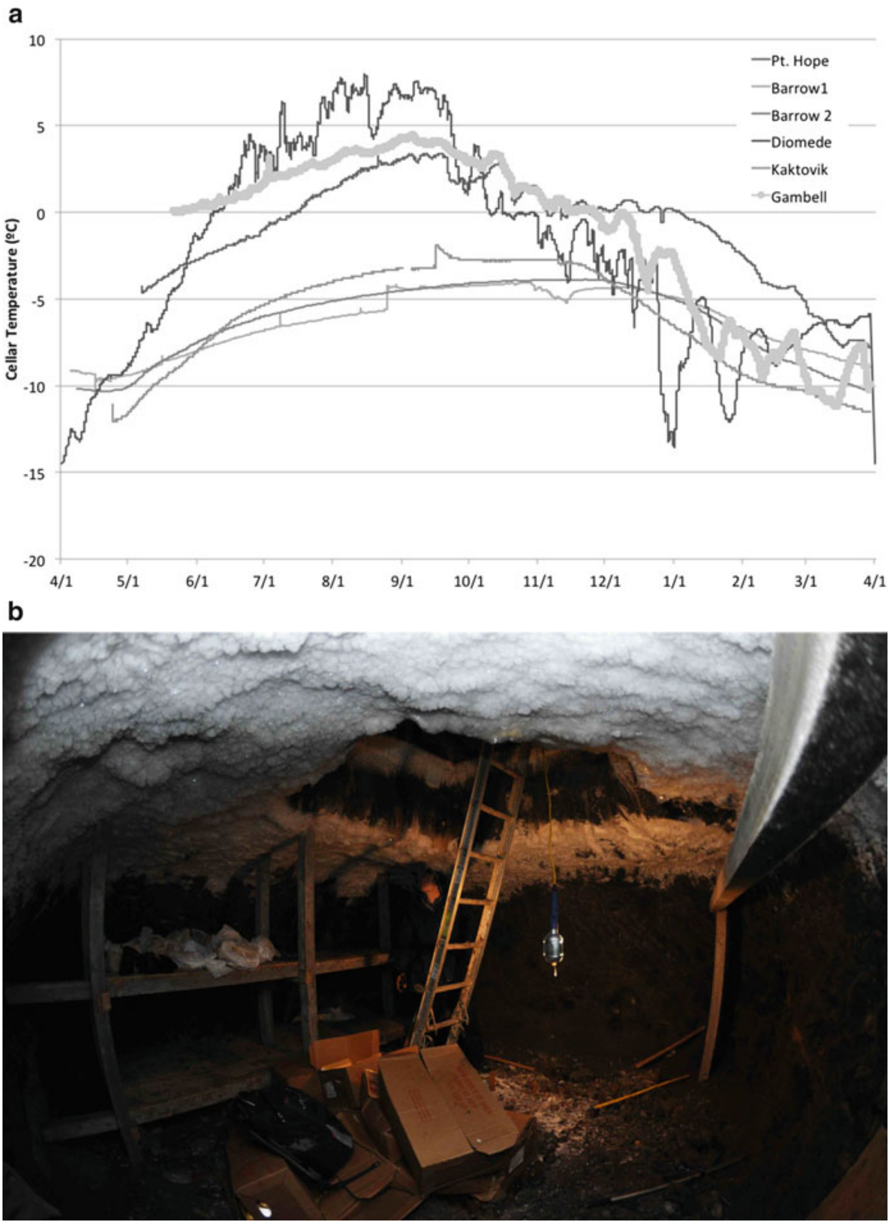

Fig. 17 Annual temperature of ice cellar (**a**) and cellar with whale meat (**b**)

of local communities. Long-term monitoring may yield useful climatic and permafrost information. This study shows that the temperature regime of ice cellars is quite different north and south of Point Hope. The primary use of ice cellars in northern communities (north of Point Hope) is storage of whale or other meat

(Fig. 17b). However, the primary use of ice cellars in southern communities (St. Lawrence Island, Diomede Island, and the Seward Peninsula) is between November and May, mainly for fermentation of sea lion meat. The subsistence life of Alaska Natives and the permafrost temperature regime fit reasonably well in these areas. The temperature data is useful in local schools for class or independent student projects such as science fairs.

5 Evaluation

The Bering Strait School District (BSSD) was chosen as the district in which more in-depth curriculum research would be conducted, because teachers in this district already were trained in pilot testing protocol. When our program began, BSSD teachers recently had finished pilot testing several other lessons. Before teachers began pilot testing the permafrost curriculum, they attended permafrost program sessions at BSSD headquarters in Unalakleet, Alaska, as part of their broader BSSD mandatory district-wide in-service training (in August 2008 for new teachers and in October 2008 for returning teachers). Our program was invited to participate in an intensive 3-day workshop for teacher representatives from each of the BSSD's 15 schools (November 16–18, 2008). To keep costs manageable, two representatives from each BSSD school attended this workshop. These representatives were responsible for sharing the training with other teachers upon return to their schools.

During the workshop, we provided a detailed overview of permafrost geophysics, describing soil properties in the Arctic, heat transfer, and the moss insulation buffer zones between the atmosphere and the ground. We also took teachers on a field trip to a nearby school to show them a model of a permafrost monitoring station. During the field trip, we explained how teachers could determine permafrost temperature and permafrost active layer depth in each rural community. Pilot testing protocol required BSSD teachers to:

1. Retrieve all permafrost curriculum resources as they became available (classroom lessons on permafrost + interactive multimedia activities + other resources, such as the TunnelMan videos and comic strip booklets) from the PALM Program website
2. Implement the permafrost curriculum with indigenous students in multi-age classrooms in rural BSSD schools
3. Participate in associated permafrost curricular activities (online videoconference lectures + online scientist mentorship)
4. Review, comment on, and suggest revisions for all permafrost curriculum resources, sending comments monthly by FedEx or by e-mail to Yoshikawa (University of Alaska Fairbanks)

At each school site, two boreholes were drilled. Into one hole, a data logger was inserted, which gathers data that can be used to show slow change in permafrost over time. In the other hole, a frost tube was inserted that contains colored water.

Table 2 PALM (ACMP) Program student pre-/posttest Wilcoxon signed-rank analysis results (Larson et al. 2009, p. 28)

Year	Number of students	Average pretest	Pretest std. deviation	Average posttest	Posttest std. deviation	Average improvement	*Z* score	*P*
PY3	186	19.3 %	27.7 %	93.6 %	12.1 %	74.3 %	11.687	<0.001

During on-site Technology Workshops, we explained how students could measure the depth and rate of freezing and thawing by taking measurements during key moments in the fall, winter, and spring. We returned to the communities annually to help students download data from permafrost observatory data loggers. The mechanics of these large data download "dumps" were described, with an explanation of how they provide comprehensive information about permafrost temperature over the course of a year.

Following instructions outlined in the permafrost curriculum, BSSD students were able to perform various analyses on the data to determine the depth of the active layer and the time and rate of its freezing and thawing.

After pilot testing the permafrost curriculum in BSSD classrooms throughout the year, two representatives from each BSSD school met at University of Alaska Fairbanks to review their experiences and to share recommendations on all facets of the permafrost curriculum from other staff at their schools. At the culminating workshop, teachers from each BSSD school used student achievement scores (from this program-created pre- and posttests) to emphasize their revision suggestions.

The Wilcoxon signed-rank test was used to assess if statistically significant differences occurred between pre- and posttest scores. The Wilcoxon signed-rank test is a nonparametric test for the significance of the difference between the distributions of two related samples involving repeated measures or matched pairs. Like the *t* test for correlated samples, the Wilcoxon signed-rank test applies to two-sample designs involving repeated measures, matched pairs, or "before" and "after" measures. The Wilcoxon signed-rank test was used rather than a *t* test because this program's pre- and posttest student data did not fit a normal distribution. An α-level of 0.01 was used to assess significance, meaning that the chances of obtaining a significant result when the underlying distributions were not significantly different are less than 1 %. External analyses of pre- and posttest results indicate that, overall, students' average improvement was 74.3 % ($n = 186$), a significant improvement ($Z = 11.687$, $P < 0.001$). The PALM Program, part of Arctic Climate Modeling Program (ACMP), student pre- and posttests administered provided data on growth in student knowledge and learning of climate science and inquiry/process skills. Students demonstrated an average increase in achievement of 74.9 %. An objective rubric was used to grade each pre- and posttest question. To ensure the validity of each score, two ACMP staff members individually assessed each pre- and posttest item. External analyses of pre- and posttest results show significant improvement in student Science, Technology, and Math (STM) knowledge and skills. "ACMP PY3" corresponds to the year the permafrost module (PALM) was used (Larson et al. 2009) (Table 2).

6 Summary

The intellectual merit of this program is that it will advance knowledge of our climatic system and the thermal state of permafrost as a complex process that is spatially and temporally quite variable. This is the first time that we have obtained a high-resolution spatial data set for Alaska and other permafrost regions. The climatic system of the cryosphere has an important influence on global climate. Monitoring the thermal state of permafrost by measuring borehole temperatures is one of the methods that can be used to understand climatic trends. The degradation of permafrost is triggered by the length of the active layer freezing period; that is, seasonal lengths are an important factor. Implicit in many of climatic change reports is the desire to develop a sustainable scientific infrastructure to address needs, among which is the establishment and maintenance of long-term observational networks. The Permafrost/Active Layer Monitoring Program provides opportunities for field experience and educational participation at levels ranging from elementary school to high school. The program will help to provide high-resolution spatial distribution of the thermal state of permafrost, especially in Alaska, and will improve the general knowledge of Earth's climatic pattern. The program also offers an opportunity for students to take part in understanding climatic systems. This project highlights the interaction between permafrost, the active layer, hydrology, and the climate system of the cryosphere, and provides a strong educational outreach program involving remote communities.

Overview

Background and Motivation

– The Permafrost/Active Layer Monitoring Program is an ongoing project that builds on work begun in 2005 to establish long-term permafrost and active layer monitoring sites adjacent to schools in Alaska and in the circumpolar permafrost region.
– About 200 schools in Alaska are involved in the project. The monitoring sites collect temperature measurement data on permafrost and the length and depth of the active layer.
– This information is important because changes in permafrost conditions affect local ecosystems and hydrological regimes and can influence the severity of natural disasters.

Innovations and Findings

– Changes in climate, length of seasons, and permafrost conditions directly impact natural resources and subsistence activities; thus, the information obtained from the monitoring sites has relevance to the communities and the students involved.

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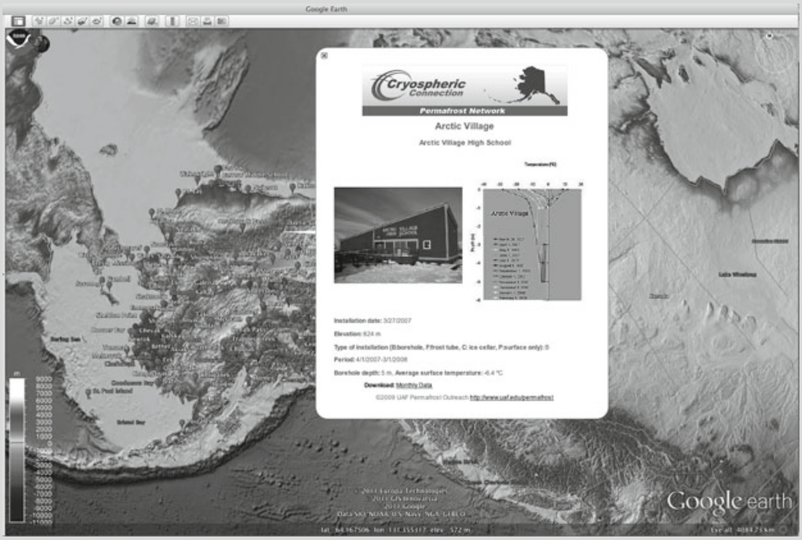

Fig. 18 Example of data archiving with Google Earth interface

– The data gathered from these stations are shared with other schools and made available to the public through the PALM Program website as well as by using Google Earth interface (Fig. 18).
– For public lectures and classroom instruction, the video series, "TunnelMan," has proven to be one of the most effective teaching tools for students. This video series appeals to students in general, but it is especially successful at holding the attention of students who have attention-deficit challenges.

Implications for Wider Practice

– Obtained data sets are not only useful for class lessons but also very helpful for science community as well as engineering purposes as they relate to communities infrastructures.
– Pre- and post-assessments administered to students provide data on growth in student knowledge and learning of permafrost science and inquiry/process skills.
– About 200 points of temperature measurements sites reveal the thermal state of permafrost in Alaska. We have a better understanding of and more accurate information on the distribution of permafrost and thermal conditions of each community. In addition to extending our knowledge of the environment of the cryosphere, the program involves school-age students in hopes of inspiring a new generation of scientists to continue this study.

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The Salish Sea Expedition: Science Outreach from the Gangplank

K. Westnedge and A. Dallimore

1 Introduction

It is becoming more widely recognized that geoscientists lack the training to communicate their science effectively to the public and policy makers and have a somewhat poor track record in doing so. This is particularly important for those geoscientists whose research has an impact on public policy and community sustainability in areas such as landslides, floods, earthquakes, and other natural hazards, some of which are arguably going to increase in frequency and timing under global climate change (Liverman et al. 2008). It is an enormous challenge to communicate the implications of geoscience issues in language that does not lose a general audience in jargon yet does not gloss over real scientific uncertainties. For example, in recent years climate scientists in particular have been struggling with issues of communication of science to the public, and a growing body of literature is helping in bridging the disconnect between climate science and climate policy (Environmental Protection Agency 2012). If, as a scientist, you aren't able to translate your science to the public realm of comprehension, you're leaving that task in the hands of people who may not understand the nuances of the research – you've jumped off the ship and are swimming with sharks.

Perhaps there is no better example of this than the trial that challenges the role of science in L'Aquila, Italy. The court will decide if six Italian seismologists and one government official are responsible for the deaths of 309 people, injuries to more than 1,500, and the destruction of infrastructure that resulted in the displacement of 65,000 people from their homes, following an earthquake on

K. Westnedge
Natural Resources Canada, Ontario, Canada

A. Dallimore (✉)
School of Environment and Sustainability, Royal Roads University, Victoria, Canada
e-mail: Audrey.dallimore@royalroads.ca

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April 5, 2009 (Hall 2001). With over 300 witnesses to be called, the trial is expected to reach a verdict by the fall of 2012. The prosecutors accuse the seven of "negligence and imprudence… of having provided an approximate, generic and ineffective assessment of seismic activity risks, as well as incomplete, imprecise and contradictory information" (Hall 2001).

As the 2011 Nature article by Hall states, the seismologists are not on trial for failing to predict an earthquake; they are on trial because they failed to communicate the risk of an earthquake to the public and public officials. This is a clear demonstration of the disconnection between the scientific community and the publics' understanding of science. A citizen of L'Aquila, Vincenzo Vittorini, is quoted in the article saying, "I feel betrayed by science…either they didn't know certain things, which is a problem, or they didn't know how to communicate what they did know, which is also a problem." Although global condemnation of the trial has been expressed by many in the scientific community, the Nature article suggests that accusations of "scientific negligence" may become more common as "extreme" natural disasters associated with global climate change events occur. Even more troubling, right at the moment when scientists are most needed to communicate our scientific knowledge and uncertainties with clarity, the L'Aquila earthquake trial may have the opposite impact of having a "chilling effect on scientist's willingness to share their expertise with the public" (Hall 2001).

2 The Salish Sea Expedition, British Columbia, Canada

The Salish Sea Expedition was an attempt to bridge the disconnect between the scientific community and public understanding of science by stepping out onto the gangplank of public outreach – over waters that aren't always comfortable or familiar for scientists. In October 2010, the Salish Sea Expedition took a Canadian marine research vessel, the *CCGS* Vector, to five communities around the inland Salish Sea, British Columbia, Canada, during the Canadian Science and Technology Week. The Salish Sea, named after the Coast Salish people who lived on its shores for thousands of years, is the new official name for the body of water crossing the international border and encompassing the inland coastal waterways of southern British Columbia, Canada, and Washington State, USA. It includes the Strait of Georgia, Juan de Fuca Strait, and Puget Sound. The densely populated shores of the southern regions of the Salish Sea, similar to the L'Aquila area in Italy, are at risk from major earthquakes and tsunamis due to the proximity of the Cascadia subduction zone just offshore the Pacific coasts of the USA and British Columbia (Clague and Turner 2003).

The objective of the Salish Sea Expedition was to bring marine geoscience topics to high school students and local community members. Small communities on the coast of British Columbia can be isolated by both land and sea, and community members don't enjoy the same access to centers of learning such as museums and universities that exist in larger communities. With a small budget, we weren't able to compete with richer organizations and events in the large population centers.

Fig. 1 High school students from Salt Spring Island in British Columbia, Canada, leave their afternoon tour of the Canadian research ship, the *CCGS* Vector, during the Salish Sea Expedition, in October 2010. The goal of the Salish Sea Expedition was to connect students and community members with the scientific research being done in their local region and give scientists and community members an opportunity to meet face to face and discuss how the science done on *CCGS* Vector is helping their communities plan for climate change and long-term community sustainability in this tectonically active region

By going to small communities, we were able to utilize local newspapers' free community announcement pages, work with individual schools, and have large cross sections of society attend the event. For 1 week, the ship *CCGS* Vector became a floating, interactive science exhibit. Over 2,000 students and community members were invited to tour and talk to working scientists about the science performed on the ship. Information was specifically tailored to link scientific research with the local areas, including how scientific research is helping those communities to plan for climate change and long-term sustainability (Fig. 1).

Each morning the ship docked in a new community. High school level students visited science stations set up around the ship, including stations on sediment coring, plankton sampling, multi-beam imaging, and visits to the bridge of the ship and safety stations. First Nations students in each community were specifically targeted as a group underrepresented in science and technology. Small groups of students talked directly to scientists about the equipment on board the ship, what research is performed, and how fieldwork translates to work in the lab and eventually policy by decision makers. By demonstrating how the science specifically impacts the region they live in, students were able to see the value and importance of the research and how it directly relates to their lives. In the afternoons, members of the community were invited aboard the ship for the same tour and access to information. From these community tours, we learned that we get a lot of "bang for our buck" by visiting smaller places because everyone in the community comes out to an event.

The limitations of the Salish Sea Expedition were both geographical and confined by tight ship spaces. Scientists and Coast Guard crew on board the ship during the expedition used blogs to describe the event each day. The goal of the blog, website, and two videos created for YouTube was to address the limitations and reach a wider audience beyond the confines of the ship. In a future event, these activities could be further expanded. However, much of the value of the event was having students and members of the public physically explore the ship and talk to the scientists in person. They were able to see scientists out in their environments doing exciting research near their local communities and widening the base of environmental knowledge in the region. And, by tailoring the information to each community, the science became meaningful because people could see how science had a role in their everyday lives.

3 Planning for the Salish Sea Expedition

The Salish Sea Expedition was a unique collaboration between three federal government departments: the Canadian Coast Guard, two Canadian universities, and a private sector aquarium. Development and implementation of the Salish Sea Expedition involved enthusiastic staff of local universities, the Government of Canada, and private organizations, many of whom volunteered their time and squeezed in the planning and writing activities around already full schedules. In the competitive world of science, it can be a difficult choice to dedicate time and energy to outreach while one's peers are using that time to write the always pressing research grants and papers. In the USA, the National Science Foundation has an outreach component to every research grant application requiring a "broader impact statement." This goes a long way to promoting science outreach as part of the stewardship of a scientist's profession and as an important outcome of public research dollars. Such a system in Canada would perhaps also encourage scientists to participate in science outreach activities and help to develop best practices for outreach. It is important to note that although the Canadian federal science funding body, the Natural Sciences and Engineering Research Council of Canada (NSERC), does not require an outreach component of research grant applications, the seed funding for the Salish Sea Expedition came from an NSERC PromoScience grant, a program designed to foster science outreach activities.

The expedition planning team had a multidisciplinary background, including scientists, communications and media specialists, educators, and public outreach specialists.

A similar structure functioned on the ship during the event, with scientists specializing in marine geology, oceanography, and multi-beam technology. Scientists were chosen based not only on their area of research but especially for their ability to explain scientific concepts to people with a variety of educational backgrounds. They were also provided with media training before the event – how to pick a few key messages they would like to get across to their audiences. The Coast Guard crew were also active participants during the event and, while not chosen specifically for their ability to talk to the public, very quickly picked up on the rhythm of outreach activities. Having multidisciplinary groups involved in the project allowed tasks to be assigned to expert groups and ensured a coordinated approach to all aspects of the events.

Because of the varied goals and interests of the organizing parties, it was essential to establish a common goal, key messages, and media strategy to which all members could agree. The overall goal of the event was to interest students and community members in the marine environment around them. The hoped-for outcome was that some of the students will consider a career in science or technology, and that the community members have more information on the environment they live in and some of the geohazards, such as earthquake risk, tsunami, and climate change, that may have an impact on the future and livelihoods of their communities. All members of the planning committee agreed to the goal, and key messages were developed to promote that goal. Committee members also agreed to a coordinated media strategy: all media releases, communications activities like video and blogs, and interviews were developed, approved, and coordinated by the group but with a single person designated as the media contact. This allowed the media contact person to develop a relationship with local media and communities but, perhaps more importantly, presented a seamless, professional "face" for the event.

4 Salish Sea GeoTour Guidebook and Map

As a legacy item, the Salish Sea GeoTour guidebook and map were created during the Salish Sea Expedition. Two thousand copies of the maps were handed out to visitors of the ship. The guidebook and map are government publications by Natural Resources Canada and part of a GeoTour series (Turner et al. 2009, 2010, 2011).

The guidebook and map use a combination of multi-beam imagery, photos, maps, and snapshots of geological information to explain the geology of the Salish Sea region in a format that is easily understandable and appealing to people with no or little education in geology. The snippets of information and visual appeal of the publication were designed to create an interest in the geology of the region for a reader who would not normally pick up a wordier, more scientific publication. The balance between providing some information – but not too much – and written in a format that would be accessible to the target groups was achieved by a collaborative effort between experienced writers and graphic designers with only a basic geological understanding and scientists who perform the research in the geographical areas described in the guidebook. It was a collaborative effort, and a unique and fruitful learning experience for everyone involved.

During the writing process, the biggest "light-bulb" moment for the communications staff was recognizing that scientists see and understand the world very differently than the public does. A "simple" geological concept or method for a scientist can be a completely foreign concept in the public realm of knowledge. For example, text in the guidebook says, "You're looking at granitic bedrock that was once far below the Earth's surface but has been pushed upwards between 175 and 45 million years ago." Editors kept changing it to *45–175 million years ago* because in the public realm of knowledge, the lower number, 45, should come before the higher number, 175. For someone with a nonscientific background, it made perfect sense but was of course completely incorrect.

The scientists' "light-bulb" moment came during the call for photos for the map and guidebook. The communications staff thought they would get lots of great photos of people working in the field, yet instead they got a lot of photos of rock and perhaps a pencil or ruler to show scale. Scientists were surprised to learn that pictures of geologic features are not as interesting to the public as they are to scientists. They learned that every research field trip should include taking some photos that are suitable and intended specifically for public outreach. For example, attractive and compelling photos of geoscience features, which also contain people working, can help the public connect more readily to the science. By having a human in the photo, it makes the science accessible: "what is that person doing?" and leads into the "what" and "why" of the science. Often, scientists are trained to keep "people" out of their writing, but for public outreach, we need to put the "people" factor back in. Our experience during the Salish Sea Expedition was that by adding the "human element," we were able to draw the public into the science and give them a starting point for understanding scientific concepts by making the science meaningful to them.

As another example, during the creation of the guidebook, we struggled to find a way to explain glacial loading and rebound. Our test readers weren't able to actively understand the concept because they couldn't visualize how it works. Once we added in that glacial loading and rebound is like pressing a hand into memory foam, the concept became much easier for them to grasp. Many people understand how memory foam works, so we were able to say the hand pressing into the foam is like an ice sheet, and even after the hand/ice sheet is removed, the foam/land takes time to rebound. By using the human element – memory foam – to explain the scientific concept, guidebook readers were able to relate the science to their own human experience and understanding of a concept.

These examples demonstrate just how differently the public and scientists see and understand the world. They're often speaking totally different languages even when both sides think they're being understood. To be considered credible and unbiased, scientists often remove all reference to people in their discourse. However, to make science more accessible, the public needs to have the human element in the picture. The human element helps the public to relate science to their own lives and experiences. Scientific language can be very exact, while public language is not.

We hope that some of the students who visited the ship will 1 day choose a career in science because they were able to imagine themselves in that role during the

Salish Sea Expedition. As a result, the Salish Sea Expedition was a resounding success judging by local community comments and interest.

Public outreach is a leap out onto a gangplank, but if we don't learn how to do it well, there will be more situations like the L'Aquila trial in Italy.

Overview

Status Quo and/or Trends

– On a small scale, our experiences with both the Salish Sea Expedition and creation of the guidebook and map provide a glimpse into the disconcerting disconnect between science and public knowledge.
– If the public doesn't know and can't understand what science is telling them, we can end up with fairly frightening and possibly life-threatening situations similar to the events in L'Aquila, Italy.
– Scientists believe they are communicating their science to the public and decision makers, as the scientists did in L'Aquila, when in fact it is very easy for their audience to hear and understand a completely different and unintended message.

Challenges to Overcome

– We live in an age where communicating science to a public audience is increasingly important. Science is being used by nonscientific decision makers to make far-reaching policies.
– Science information via the Internet has created a worldwide audience but also an environment where credentials and credibility can be unknown or unproven. The validity of Internet content is a special challenge for youth, where 39 % of children aged 9–17 believe all online content is correct (Scholastic 2010). So, for example, with climate change, science has new meaning to the safety, sustainability, and future of many communities around the world.
– The challenge to scientists is to step out onto the "gangplank" of public outreach and bridge the disconnect between scientific language and public information.

Recommendations for Good Practices

– During the Salish Sea Expedition and writing of the Salish Sea GeoTour guidebook and map, we tried to put the human element into the science so people could understand and relate to our key messages.
– We talked about the research and how that science impacts their community, making the science meaningful to peoples' everyday lives.
– We put faces to the science by having students and members of the public talk to and see scientists doing the work.

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Problem-Based Learning in the Field Setting

Lung Sang Chan and Loretta M.W. Ho

1 Introduction

> We had to think everything about ourselves…Miss didn't interfere…
> We couldn't do that at school…we didn't even ask if we were right or wrong…
> It's more fun to learn in this way…we discussed…and we understood better…
> We had to discuss and analyze…it's more impressive…we understand better
> They (students) learned faster than I expected…

The above feedbacks were collected from a group of secondary school girls and their teacher after a 1-day field trip organised by us, under a government-funded project 'Problem-Based Learning in the Field Environment', in Hong Kong (Chan et al. 2005). The project intended to enhance the capability of teachers in organising field-based learning using a new approach.

Field-based learning (hereafter referred to as FBL) has a long history of development. Learning in the field enables students to contextualise and understand the ideas more deeply through direct sensory motor experiences and illustrations with real samples (Kempa and Orion 1996; Orion 1993). The field setting is also a best venue to develop inquisition in the mind of students because there are numerous ill-defined problems, which have no definite answers and can only be solved by integrating knowledge across disciplines. In the inquiry process, they learn the essential skills, which support them to become independent lifelong learners (Eshach 2007; Ramey-Gassert 1997). Previous researches indicate that students' enjoyment and

L.S. Chan (✉)
Department of Earth Sciences, The University of Hong Kong,
Hong Kong, Hong Kong
e-mail: chanls@hku.hk

L.M.W. Ho
Faculty of Education, The University of Hong Kong,
Hong Kong, Hong Kong

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engagement are higher in field rather than in the classroom (Kempa and Orion 1996; Tretinjak 2001). In short, an effective FBL design can give students a total education experience in which their knowledge, skills, mind, as well as the ability to improvise for unforeseen condition can be holistically developed.

Although it is generally agreed that FBL is beneficial for student learning, still not many teachers feel competent in conducting FBL, especially using a student-centred investigative approach (Hawley 1996; Orion 1993). Even when teachers bring students to the field, they often use a direct instructional approach to run the field trips (Tretinjak and Riggs 2008). The feedbacks shown above, to a certain extent, reflect the conventional beliefs and instructional approaches of teachers that often undermine student learning (Biggs and Moore 1993). More importantly, the feedbacks suggest how teachers' competence and student learning can be enhanced by adopting problem-based learning (PBL) in the field setting. While PBL has been adopted worldwide and is proven to be an effective curriculum and instructional approach (Albanese and Mitchell 1993; Blumberg 2000), its applications in field setting to enhance teaching and learning are largely unexamined. This chapter introduces the new FBL approach and the factors to be considered for its successful implementation by teachers.

2 Conventional Approaches in Field Instruction

Prior researches suggest that the beliefs and practices of teachers have a strong influence on the conceptions and approaches of students to learning, which in turn affect their learning outcomes (Biggs and Moore 1993; Schoenfeld 1998; Zimmerman and Risemberg 1997). In FBL, we can classify the approaches that geoscience teachers commonly use in the following categories.

2.1 Field Setting as an Outdoor Classroom

In this approach, teachers deliver lectures directly in the field setting, which is generally an outdoor environment, drawing examples that are readily accessible at the field site. No lecture on the same subject is given prior to the field trip; the students learn all the concepts on the spot. Instructions are delivered in the same manner as in a classroom lecture, except for the change in the learning venue.

2.2 Show-and-Tell Excursion

Teachers first teach the concepts in a classroom lesson and then emphasise on validating the concepts with examples in the field excursion. Teachers themselves plan the excursion route, along with the observational points and the contents to be covered.

2.3 Field Worksheets

Students follow the instructions of a worksheet, go to a particular locality of interest, and answer a set of questions or undertake certain tasks. This approach is easy to manage from the teacher's point of view as the field activities and questions raised by students can be fully anticipated.

2.4 Guided Field Investigation

Students are given a topic and are instructed on the objectives of the study. They systematically follow the procedures that are outlined by the teacher to collect and analyse data and draw conclusion. This learning process essentially requires the teacher to guide the students throughout.

Although these approaches can be effective, however, in particular contexts, they are generally teacher centred, requiring the teacher to take over a large part of the process, including planning, designing, organising, and executing the field activities. The role of students is often limited to that of a passive receiver reacting to the teacher's instruction and questioning. This often decreases the motivation of students, and merits of the field activities are compromised. Also, students may only perceive FBL as to achieve the task-completion goal or the instructional goal rather than the knowledge-building goal (Bereiter and Scardamalia 1993). In our view, this problem can be solved by adopting a PBL approach, as students will be engaged to co-construct knowledge through productive discourse practices (Hmelo-Silver and Barrows 2006).

3 PBL in the Field Setting

3.1 What Is PBL?

PBL was first defined by Barrows (1982, p.1) as 'a learning method based on the principle of using problems as a starting point for the acquisition and integration of new knowledge'. With respect to the widespread adoption of PBL by different disciplines, for different age levels, and in different content domains, Finkle and Torp (1995) defined PBL by virtue of its unique design components, students' roles, and cognitive processes, as 'a curriculum development and instructional system that simultaneously develops both problem-solving strategies and interdisciplinary knowledge bases and skills by placing students in the active role of problem solvers confronted with ill-structured problem that mirrors real-world problems' (p. 1). Their definition highlights that PBL is not simply pedagogy but a learning system. Prior researchers reviewing PBL have reported its apparent benefits to student learning (Albanese and Mitchell 1993; Blumberg 2000; Dochy et al. 2003; Veron and Blake 1993).

In contrast to unguided inquiry learning, PBL is a highly scaffolded inquiry learning (Hmelo-Silver et al. 2007). Barrows (1986) highlighted six core features characterising PBL: (1) student-centred learning, (2) small group learning under the guidance of a tutor, (3) tutor acting as a facilitator, (4) authentic problems as the starting point of learning, (5) problems mediate the acquisition of the required knowledge and the problem-solving skills act as tools to solve problems, and (6) acquisition of information through self-directed learning.

Based on both constructivist and social constructivist views of learning and teaching, PBL is a highly structured collaborative learning system that aims to engage students in authentic experiences and complex problem-solving tasks, which requires them to have the access to all the three forms of knowledge: declarative, procedural, and conditional (Hmelo and Evensen 2000). Its emphasis on the acquisition of interdisciplinary knowledge, self-directed learning, deep inquiry, and collaborative problem solving makes it an effective approach for learning. Through PBL, students are able to develop solid and measurable knowledge base, self-efficacy, and intrinsic motivation, also metacognition and a wide range of skills that enable them to become self-directed learners (Hmelo and Evensen 2000).

3.2 The QEF Project: PBL in the Field Environment

While PBL has been increasingly recognised and adopted by higher education in Hong Kong (Ciocca and Whitehill 2000; Ho and Chan 2009), it is yet not commonly practised in secondary schools. The New Senior Secondary (NSS) curriculum that was implemented years ago has called for a strong emphasis on inquiry-based, self-directed, reality-based, and interdisciplinary learning. Several curricula require FBL as part of the school-based assessment. This development has led to the need for new learning approaches, both in the classroom and the field setting. Considering the effectiveness of PBL in preparing students to become independent lifelong learners and as suggested by prior literatures, we conducted a project in 2003–2005, which was supported by the Quality Education Fund (QEF) of Hong Kong Education Bureau. The project aimed to explore the feasibility and effectiveness of adopting PBL as the main field instruction.

This project highlighted the component of 'field' as numerous complex and ill-structured problems that are readily in the field environment, making it an authentic learning context for students to explore (for details, see Chan et al. 2005). While we aimed to develop in students a 'PBL frame of mind' (Sage 2003), we considered it equally important for teachers to have such a mindset so that they could develop a new paradigm to manage FBL. Thus, the project was structured into two phases consisting of teacher and student development programmes in the form of PBL workshops and tutorials in the field context. The following research questions guided the project:

1. What are the effects of the teacher development programmes upon teachers' competence in conducting field PBL?

2. What are the effects of the student development programmes upon student learning in the field?
3. Can PBL be an effective field instruction? If yes, how?
4. What are the considerations in adopting field PBL?

4 Method

4.1 Participants

The present project was a 2-year study involving 298 teachers and 501 students from different secondary schools in Hong Kong. Teachers, through open recruitment of the project, participated in the field PBL teacher development programmes organised by the project team. The teacher development programme consisted of two rounds of field PBL training camps. After the teachers completed the two training camps, they were encouraged to bring a group of students (5–6) to attend the student development programme (mainly a field PBL training camp). Upon completion of the programme, both the teachers and students were awarded with a certificate. A total of nine teacher development programmes and eight student development programmes were organised.

4.2 Instructional Design of the Project

4.2.1 Phase One: Teacher Development Programmes

The PBL teacher development programmes were intentionally designed to situate participants in authentic field PBL experiences. Situated learning (Lave and Wenger 1991) in these programmes were twofold: (1) teachers learnt by playing the role of active learners themselves to experience the field PBL activities offered to students and (2) teachers learnt by playing the role of facilitators in adopting the field PBL.

Instructional Design of the Programmes

The programmes aimed to help teachers to progressively develop a clear understanding of PBL and to familiarise with the procedures in conducting field PBL (see Table 1). These aims were embedded in two rounds of a 2-day PBL field training camp. The training camp was held in one of the field centres of Hong Kong.

The contents for both rounds of the training camp were identical except for the participants' roles. In the first round, teachers were presented with a problem (Fig. 2) for group analysis, and experienced PBL tutors were assigned to facilitate the group learning. Participants developed their understanding by situating

Table 1 Overview of the 2-day PBL field training camp

Activity	Content
Programme objectives: at the end of the training camp, participants will be able to:	
Explain the basic theories and concepts of PBL	
Execute the procedures in conducting field PBL	
Identify the key features of a good problem	
Recognise the essential facilitating skills in managing field PBL	
Identify the differences between field PBL, traditional field learning, and other learning instructions	
Sum up the considerations in adopting field PBL	
Establish a field PBL teacher development network	
Day 1	
Introductory session	Overview of the programme objectives and run down
PBL hands-on experience (1)	(a) Participants work in groups as learners for a PBL task (b) Facilitated by an experienced PBL tutor, each group analyses a given problem statement by: Identifying facts, ideas, and learning issues Formulating investigation plan to be carried out in the field environment (c) Group presentation and refinement of the plans
Lunch	
PBL hands-on experience (2)	(a) Facilitated by the PBL tutor, each group works collaboratively on their field investigation (b) They have to finish data collection within a marked duration of time
PBL hands-on experience (3)	(a) Participants get back to the camp site and finish: Analysing data, drawing inferences and conclusion Generating new investigation questions (b) Group presentation and peer critiques of the results
PBL forum	Open discussion facilitated by the project team on: (a) Learners and facilitators' experience (b) Characteristics of PBL (c) Advantages and constraints in adopting field PBL
Programme evaluation (1)	Self-evaluate and reflect on learning process and products
Dinner and fun	
Day 2	
Geological field trip	(a) Led by an expert geologist, participants join a formal field trip studying the geological features around (b) Participants practise basic field observation skills
Lunch	
PBL forum	Open discussion facilitated by the project team on: (a) Differences between field PBL and traditional field learning (b) Conceptualisation of field PBL (c) Considerations in design and implementation of field PBL
Programme evaluation (2)	Self-evaluate and reflect on learning process and products
Summary and closing	

themselves as ‘learners’ to undergo an authentic field PBL process. Simultaneously, they observed the facilitator’s skills. In the second round, participants developed a deeper understanding by situating themselves as ‘facilitators’. Supported by an experienced PBL tutor, each participant facilitated a new cohort of ‘teacher-learners’ and underwent the same field PBL process. To establish productive learning communities, forums were provided for facilitators and learners to reflect on their learning, to compare conventional field trips with field PBL, to clarify misconceptions, to enquire potential problems, and to work out effective strategies for future PBL design and implementation.

The PBL Process

The classical version of PBL (Barrows 1985, 1988) has two key features: (1) the use of a rich problem that allows free inquiry by learners and (2) the other is student centred. The core of PBL is the tutorial, which consists of four phases: introductions and climate setting, starting a new problem, problem follow-up, and post-problem reflection (Barrows 1988; Hmelo and Evensen 2000). The PBL model employed herein was a modification of Barrow’s classical model, a seven-step cyclical learning process (see Fig. 1).

The facilitator divided the learners in groups of five to seven. The learners got to know each other, assigned each other a role (group leader, recorders, and presenters), and established ground rules for an effective collaborative learning. The facilitator used the whiteboard (or big drawing papers) for the learners to record the discussed ideas in columns (see Table 2). This made the thinking process and products visible throughout the tutorial process.

The facilitator began the PBL tutorial by presenting a problem (step 1) for the learners to read and analyse. The problem design can be understood as a process of developing scenarios that are specifically selected and structured so that learners will necessarily encounter important curriculum objectives and standards while problem solving (Torp and Sage 2002). Figure 2 is an example of the problems that we designed for the learners to study the impacts of tourism on natural localities and to discuss the merits and the adverse effects of World Heritage designation.

While the design of this problem was based on the actual scenarios of a famous geological site called Ma Shi Island, it consisted of partially real and partially fictitious information. Moreover, it was intentionally ‘messed up’ and ill structured, so as to leave gaps in information and to avoid being overly leading. Mr. Wong and Nature Conservancy were fictitiously added to highlight certain controversies and compelling dilemmas of the society towards specific issues. The problem was in the statement form, which did not contain any questions. It were the learners who generated the learning issues related to those controversies and compelling dilemmas for group field investigation.

Prior to field investigation in Ma Shi Island, learners worked together to analyse the problem (step 2). They spent about 2 h, critically identifying ‘what they know’, ‘what

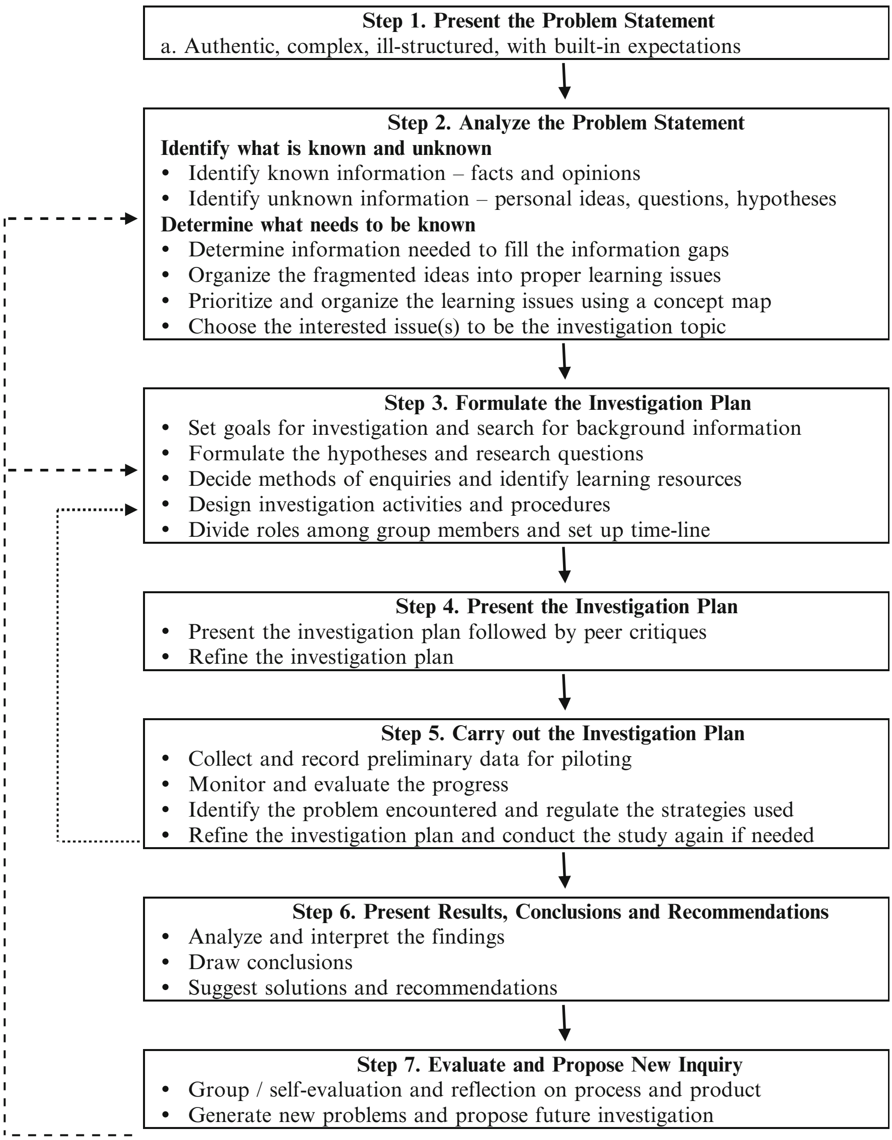

Fig. 1 The modified PBL model

Table 2 Whiteboard setting

What you know… (known information)		What you do not know… (unknown information)	What you need to know… (learning issues)
Facts	Opinions	Ideas/questions/hypotheses	Issues and questions worth exploring

> Ma Shi Island has been a destination for geological field study. To promote geological conservation, government is planning to transform the place into a Geopark and eventually apply for world heritage status. Having realized the potential for increased visitors, Mr Wong, a local villager converted his farmland nearby into a resort, in the process removing a large number of trees. Nature Conservancy strongly criticized Government for disguising a tourism development plan as a conservation initiative.

Fig. 2 Example of a problem

they do not know', and 'what they need to know', to fill the information gaps. They identified and recorded the known (facts and opinions) and unknown information (personal ideas, possible reasons, questions, and hypotheses), the concepts that they did not sufficiently understand, as well as the 'learning issues' to fill the information gaps. For this particular case, they were expected to derive learning issues pertaining to the scientific merits of the field locality and conflicts between tourism development and natural conservation. A concept map was used to organise the learning issues and the relevant concepts to see their interconnectedness from multiple perspectives. Learners then chose the learning issues that they were interested in to formulate an investigation plan (step 3) for field investigation.

During the PBL tutorial, the facilitator guided the learners to undergo the PBL process stepwise with minimal interference. The facilitator's role was to assure equal participation and high-level interaction among the learners. When required, the facilitator also confronted the learners to help them realise what they did not understand. Occasionally, the facilitator modelled metacognitive questions to encourage reflective thinking by pushing the learners to explain why they considered a particular solution to be good or why they considered a particular piece of information, about the problem, to be useful. While working on the problem, the learners simultaneously took an active role in questioning, hypothesising, clarifying, explaining, summarising, and confronting others' ideas and making suggestions. The recorder(s) noted all the discussed ideas to help the learners keep track of the group's thinking process and to provide a focus for negotiation and reflection (Hmelo and Evensen 2000).

By the end of the tutorial, each group formulated an investigation plan testing their hypotheses, with topics varying from geological features on the island to the pros and cons of World Heritage designation. They then presented their plans, responded to peers' critiques, and refined their plans (step 4) before carrying out the field investigation (step 5). The peer critique session was particularly essential because cognitive conflicts took place only through peer questioning and confrontation. Through clarifying and explaining, learners thought more critically and thoroughly about their plans. They also learnt how to set up a better plan from their peers. The facilitator was the last to comment.

After refining the investigation plan, each group carried out their investigation in Ma Shi Island. In the field site, they observed the environment, marked the check points for data collection, divided the work among members, collected and recorded

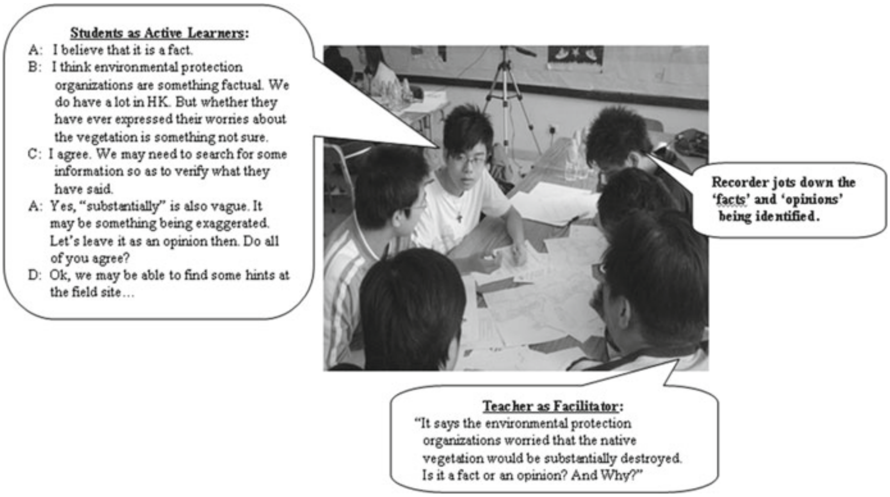

Fig. 3 Teacher facilitated the students to analyse the problem

the preliminary data, monitored and evaluated the work progress, identified the problems encountered, used improvisation skills and regulated their strategies to solve the problems, refined their plan when necessary, examined the collected data, and planned for the next round of data collection. Finally, learners analysed and interpreted the data, drew conclusions, made suggestions, and presented the results (step 6). Learners were reconvened to evaluate their performance in groups, shared what they had learnt, reconsidered their hypotheses, and proposed the new inquiry (step 7). While steps 1 and 2 were unique PBL procedures, steps 3, 4, 5, 6, and 7 were typical inquiry procedures.

4.2.2 Phase Two: Student Development Programmes

The PBL student development programmes were designed not only to enhance student learning but also to develop the confidence and main strategies of teachers in adopting PBL. Teachers who underwent the two rounds of field PBL training were invited to bring a group of secondary school students to join the student development programme. Supported by the project team, teachers acted as 'problem solvers' in conducting the field PBL activities. Unlike the teacher programme, the student programme was a 1-day PBL field activity. Nevertheless, the PBL process for students was the same. During the PBL process, teachers played the role of facilitators while the students acted as active learners analysing the problem collaboratively (Fig. 3). Follow-up discussions were organised for teachers to reflect, enquire, and seek solutions together.

The following pictures show one of the field PBL activities in which students studied the geological, ecological, environmental, political, economical, and cultural

Fig. 4 Students scaffolded each other to critically analyse the problem

issues related to a government project, which proposed transforming an important field site into a famous tourist site of Hong Kong (Chan et al. 2008).

As students were more adapted to the learning procedures, the provision of scaffolds gradually shifted from the teacher to the students (Fig. 4). Students helped each other to understand the situation by raising questions, explaining their understanding, hypothesising, and identifying the information gaps of the learning issues that needed to be filled through field investigation. At the end, students discussed and compromised what would be most important and interesting to study.

After determining the study topic in the field, students formulated and presented their investigation plans (Fig. 5) (Chan et al. 2008). They refined their plans after receiving peers' critiques as an essential learning process before carrying out the actual field investigation.

The field investigation was entirely a self-directed learning process. Students worked cooperatively to collect and analyse the field data. Finally, they had to draw conclusions and present their findings (Fig. 6) (Chan et al. 2008), respond to peers' critiques, evaluate their learning process and products, and propose further investigation or new inquiry. To help teachers re-conceptualise field PBL and plan for future school implementation, follow-up discussions were organised for them to reflect, enquire, and seek solutions together.

4.3 Measures

This study employed a multi-method evaluation of the field PBL development programmes. To ascertain the extent, to which the programme activities helped enhance teachers' competence in conducting field PBL, their beliefs and practices were

Field Investigation Plan

1. **Investigation Title:**
   How would pollution affect the mud field ecology of Tai Mei Tuk
2. **Aim:**
   Investigate the relation between ecology and pollution
3. **Research Question:**
   - What does it mean by a balanced ecology?
   - How's the environment there?
   - How many no. and species of animals can be found there?
   - What's the evidence to prove whether ecology is balanced or not?
4. **Hypothesis:**
   Increase pollution→less vegetation→decrease animals on each food chain level
5. **Investigation Methods and Steps:**
   - Basic information research: recognize the original look of mangroves
   - Collect all sorts of samples (including soil)
   - Observe flora and fauna (video and photos)
   - Observe times of high tide and low tide and water levels
   - Test samples at laboratory (check later)
   - Search information on the relationship between flora and fauna, use observation to prove the information
   - Record level of oxygen (have not checked)
   - Observe possible effects on migratory birds (long term – four seasons)
6. **Resources:**
   Camera, post-it notes, containers of samples, spades, ruler, markers, binoculars, reference books, pH testers
7. **Division of labour:**
   - Sample collection (Kelie, Vicki) – soil samples, sea water samples
   - Observation (Jessie, Belinda, Kylie, Vicki) – birds, animals, recording quantity

Fig. 5 Exemplar of students' investigation plan

examined. With regard to teachers' beliefs about field PBL, written questionnaires on 'Teachers' Conceptions of PBL' were administered pre- and post-programmes. The questionnaire consisted of five main questions checking teachers' basic understanding of PBL, the differences between PBL and other forms of instructions, the commonalities and major differences between field PBL and conventional field instructions, the advantages or constraints in adopting PBL, and considerations for successful implementation. To help teachers evaluate their learning (both learner and facilitator experiences) in the teacher development programmes, they were asked to complete a 'PBL Self-Evaluation and Reflection Form'. Teachers had to evaluate and reflect on the activities that interested them the most, the 'successful' and 'bad' experiences that they obtained, the factors that contributed to those experiences, and the strategies for improvement. Lastly, they had to summarise what they had learnt about PBL. To triangulate the results, the performance and discourse of teachers in the programme activities were video-taped for analysis. With regard to student learning, students were asked to complete a 'PBL Self-Evaluation and Reflection Form', which was similar to the one used by teachers. In addition, the performance and discourse of students in the programme activities were video-taped, and their work was collected for analysis.

Student Presentation

1. **Investigation Title:**
Existing facilities and room for sustainable development
2. **Research question:**
   - What are the existing facilities at Tai Mei Tuk?
   - Are they adequate to support the future project?
   - Is there room for sustainable development?
3. **Findings:**

a. Existing facilities
Family Walk → hiking, cycling track, 3 piers, signposts, 2 bus stops, car park (150 spaces), BBQ area → (Area 1) 40 pits, (Area 2) approx 50-60 pits, 22 rubbish bins, 7 recycling bins, 1 telephone booth → emergency telephone (112), 2 stores → (cooked food, beach supplies, drinks, sun shades and boat rental), artificial lake →fishing, 2 sand beaches, 2 toilets, Scouts Training Centre → water sports, Leisure and Cultural Service Department (LCSD) → management, eateries: cafes.

b. Facilities to be added:
- parking lot for shuttle buses
- local market

c. Comments from visitors:
- advantages of site: nice view, clean, fresh air, 40% agree to good facilities
- disadvantages of site: inadequate amount of rubbish bins, pollutants on sea, air pollution visble, has limitations for tourism
- suggestions for improvement: more toilets and car parks

d. Will ↑ facilities affect more people come?
- interviewed 40 people, only 30 people answered
- agree to have beach area ↑ , but if cost HKD$70 million → × beach

e. Pollutants? → affect Ecology?
- seaside → sewage drainage (oysters, crabs, butterflies, trees)
- ↑ mangroves, not too many
- pollutant ↑, water quality ×
- return journey, muddy water, BBQ area → pollution source
- data collection next time–need to bring book, collect information, collect samples, pH paper, visit Hong Kong Observatory's website first

f. Feasibility for an Artificial bathing beach
- feasibility → if yes, pebble beach, but near mangroves, affect ecology
- × "Hong Kong Pattaya", because water sports activities would increase →destroy coastal line → suggest Eco-tour
- pollution, change the quality of H_2O
- life guards ×

g. Mud field ecology
- many mangroves → good ecology, little mangroves → pollutant ↑
- Low tide → pollutants gone
- Timely collect H_2O (once every 3 months)

h. Others
- transportation no good, half hour to go to KCR station

4. **Group Concluding Remarks:**
(Actually, we are interested in many topics. Given the limited time, we can only collect some preliminary data. Infuture, we hope to come back for a more in-depth study.)

Fig. 6 Exemplar of students' presentation

5 Impacts of the Project

The 'PBL in the Field Environment' could be considered as an innovative FBL project in Hong Kong and elsewhere, not only because it employed PBL as the main field instruction but because it emphasises on teaching and learning as an intertwined process. Participants of the teacher development programmes were not limited only to teachers who were responsible for school's FBL but across disciplines. This was essential for the future development of a school-wide field PBL curriculum innovation.

5.1 Teachers' Competence in Conducting Field PBL

To examine if the teacher development programmes helped teachers to develop competence in conducting field PBL, 'Teachers' Conceptions of PBL Questionnaires' and 'PBL Self-Evaluation and Reflection Forms' were collected. The field PBL learning and facilitating processes of teachers were also video-taped. Regarding teachers' understanding of field PBL, qualitative analysis based on their written responses of the questionnaires indicated that their understanding before the programme activities was mainly on the level of basic theoretical understanding, which could be categorised into four dimensions: (1) nature of PBL, (2) advantages of PBL, (3) learner's role, and (4) teacher's role. In the post-programme activities, majority of the teachers expressed that they had a better understanding. 'PBL design', 'PBL implementation', and 'criteria for successes' were new dimensions adding upon the original four. The increased number of dimensions suggested a broader scope of understanding and a shift of focus from basic theory to theory-practice integration among teachers. Results concerning teachers' ability in distinguishing field PBL from conventional field instructions indicated that majority of the teachers were able to give an account of the commonalities and differences between the two in terms of aims and objectives and learning and teaching approaches. Regarding teachers' perceptions of the feasibility of adopting field PBL in secondary schools, majority of them agreed that field PBL was more authentic, challenging, and easier to arouse students' interests. Students' critical thinking and problem-solving skills could be fostered. However, some expressed their concerns in actual implementation, including the inadequacy of facilitators for a large class, up to 40 students, and the difficulty in writing up a good problem. Results based on the analysis of the video-taped field PBL activities provided some evidence suggesting that teachers were able to conduct field PBL. Their facilitating skills improved over time. This was reconfirmed by the enhanced understanding, confidence, and positive attitudes of teachers towards PBL, based on their self-evaluations and reflections of the programme activities.

5.2 Student Learning

To examine if the student development programmes helped enhance student learning, students' field PBL activities were video-taped and their learning products and self-evaluations were collected. Students' performance based on the video-taped activities revealed their high motivation, active participation, high level of collaboration, and interaction during the field PBL process. The way students planned ahead, sought resources, and regulated their strategies on encountering problems demonstrated how students' cognitive and metacognitive development was enhanced. The collected learning products (e.g. the investigation plans and presentation work as shown in Figs. 5 and 6) demonstrated that students were able to work independently to produce original, organised, and creative ideas when challenged by real-life problems. Results based on students' self-evaluations and reflections of the programme activities indicated that students enjoyed the field PBL. Many of them expressed that field PBL was exciting, challenging, and thought provoking. They had the freedom to generate and prioritise the learning issues for investigation. Through group investigation, they learnt the field techniques, for example, observation, measurement, collecting samples, and evidence. The PBL process helped them acquire and integrate knowledge and skills through collaborative problem solving.

In summary, the consistent positive feedbacks from teachers and students were evidently useful to increase our understanding of how teachers and students can learn to become competent field practitioners and active learners.

6 What Makes PBL an Effective Field Instruction?

The PBL project described here illustrates how PBL can be successfully adopted in the field setting. But what makes PBL become an effective field instruction? One of the unique features of PBL is that it situates learning in meaningful problem-solving situations in which students are actively emerged into the inquiry and problem-solving process. These cannot be achieved by the conventional teacher-centred approaches in which students take a passive role waiting for the teachers to pass on information, to make decision, and to suggest solutions. PBL, however, distinguishes itself from other unguided inquiry-based learning in the following aspects (Chan et al. 2008).

6.1 PBL Emphasises Intentional Learning as a Goal of Instruction

In many schools, teachers require students to do field trips, which are decontextualised from the school curriculum. Producing the final product and skills training are seen as the end rather than the means towards knowledge construction. PBL, however, emphasises curriculum relevance. There is an intended curriculum encompassing knowledge, skills, and values that students are supposed to build upon their prior knowledge through a matrix of multiple PBL activities (Torp and Sage 2002). New learning and deep understanding are highlighted. Also, knowledge construction, advancement, and representation are seen as the ultimate goals. The intended curriculum that moves students towards a knowledge-building goal (Bereiter and Scardamalia 1993) marks the difference between PBL and the unguided or loosely designed inquiry-based learning (Hmelo-Silver and Barrows 2006).

6.2 PBL Situates Learners in Highly Scaffolded Inquiry Learning

PBL is more promising than conventional teacher-centred field instructions because it is a structured but flexible collaborative learning system, which combines metacognitive and social interactive approaches to support student learning. The scaffolded inquiry and problem-based environments allow students to engage in complex tasks that would otherwise be beyond their current abilities. Scaffolds in PBL can be the use of the whiteboard and the learning materials, also the procedural prompting given by the facilitator and the peers. Hmelo-Silver et al. (2007) explained the use of scaffolding in reducing cognitive load, providing guidance, and helping students in acquiring disciplinary ways of thinking. They pointed out that it is these functions that make learning more tractable for students by changing complex tasks in ways that make these tasks accessible, manageable, and within students' zone of proximal development (Rogoff 1990; Vygotsky 1978).

6.3 PBL Takes Cognition, Metacognition, and Epistemic Cognition All into Account

Many teachers compare PBL with other inquiry-based learning approaches and question why they need to spend time going through the long PBL tutorial. From the learning perspective, PBL is a 'recursive' rather than a 'linear' model. It highlights the notion that the learning cycle should start from 'inquiry', go through 'new learning', and end with 'new inquiry'. Coupled with cognitive and metacognitive knowledge and strategies, the unique PBL tutorial procedures are intended to foster interaction and to develop students' inquiry and systematic and higher-order thinking when immersed in an ill-structured problematic situation. It supports students' learning of how to do the task, why the task should be done that way, and how knowledge is constructed (Hmelo and Evensen 2000). Table 3 illustrates how procedures of the PBL tutorial facilitate the systematic development of cognitive and metacognitive knowledge and strategies of the learners. All these are fundamental and transferable to other learning (Chan et al. 2008).

Table 3 Cognition and metacognition development in PBL

Known	Unknown	Learning issues	Concept map	Investigation plan
Facts ↓ Opinions	Ideas/questions/hypotheses			
'Metacognition' (Conscious awareness and control of one's knowledge to understand the ill-structured problems)	'Metacognition' (Conscious awareness and control of one's knowledge to understand the ill-structured problems)	'Self-generating questions' (Formulating the fragmented unknown ideas into proper learning issues and specific questions to fill the information gaps and for deep inquiry)	'Organisation of ideas' (Organising the learning issues systematically for a holistic understanding of the topic, the interconnectedness of the issues and concepts, and the multiple perspectives involved)	'Self-directed' learning (Formulating the plan of the self-chosen topic for deep exploration)
'Critical mind' (Basic critical and analytical thinking to new information and things around)	'Inquiry mind' (Curiosity to learn by identifying the information gaps) 'Creative mind' (Making guesses and assumptions to the undefined problems)			'Metacognition' (Conscious awareness and control of one's knowledge to define the focus of investigation and plan for the action)
→	→	→	→	

6.4 PBL Emphasises on Students' Autonomy and Self-Directed Learning

In many of the inquiry-based learning, for example, in conventional problem solving, the teacher provides a well-structured case, followed by the inquiry questions. Students are often required to follow certain guidelines to arrive at the expected answers or solutions. Although PBL is a highly structured system, the ill-structured problem provided by the teacher contains no specific questions or fixed solutions. Students act as critical enquirers to generate the learning issues and also as independent problem solvers to connect, integrate, and apply knowledge throughout the learning process. This process pushes the students to think about the old concepts in new ways (Hmelo-Silver et al. 2007). The objectives, inquiry questions, methods, and outcomes of the field trip are all managed by the students.

6.5 PBL Is Highly Structured to Enhance Both Individual and Collective Knowledge

Unlike an individual or the loosely structured group FBL, where the weaker students are often left to struggle, PBL is highly structured to ensure equal participation and contribution. No student is deprived of the opportunity for making contributions and appreciating the contributions of the others. Expertise is distributed through the arrangement of heterogeneous groups maximising students' multiple intelligences. Rich metacognitive peer scaffoldings, high level of interaction, and collaboration enable students to work within their multiple zones of proximal development (Brown and Campione 1994). Student diversity can therefore be better catered in PBL.

6.6 PBL Shifts Teachers' Roles as Facilitators and Cognitive and Metacognitive Coaches

PBL can be regarded as cognitive apprenticeship (Rogoff 1990). While the students act as active learners and problem solvers, the teacher maintains dual roles as a facilitator and cognitive coach (Torp and Sage 2002). As a facilitator, the teacher must empower students to make decisions, refrain from over-participation, and must not immediately negate students' ideas. As a cognitive coach, the teacher plays a crucial role in determining the intended curriculum, providing guidance and feedback at critical time, and evaluating the feasibility and safety of the proposed plans. Without their support, the students would not be able to fully enjoy the autonomy in learning.

The above distinctive features make PBL even more promising.

7 Considerations in Adopting PBL in the Field

PBL is a highly scaffolded collaborative learning mode with learning goals clearly set and well-stated procedures to follow. While this innovative FBL approach offers significant merits over the conventional approach, the following conditions have to be fulfilled in order to implement effectively.

7.1 *The Essence of Developing Teachers a PBL Frame of Mind*

It is generally agreed that promoting change in student learning requires first changing the teacher's learning process. Many teachers hesitate to adopt field PBL because the changes required are complex that do not automatically result from ordinary teacher development programmes. While the field PBL approach aims to develop in students a 'PBL frame of mind' (Sage 2003), it is equally important for teachers to develop such a mind. In this project, the idea of 'PBL frame of mind' is viewed in two contexts: a 'PBL frame of mind in learning' and a 'PBL frame of mind in teaching'.

7.2 *Effective Teacher Professional Development as the Key to Successful Field PBL*

Murray and Savin-Baden (2000) argued that a sound teacher development programme is required for the success of PBL. Teachers must be given prior professional training for designing of good problems, strategies, and skills for facilitating the PBL activities, also assessing students. The major problem of many conventional teacher development programmes is that they are one-time events that emphasise the transmission of knowledge from experts to passive teacher-consumers. We argue that effective teacher development programme should be an ongoing learning and reflective process that must aim in changing the belief, knowledge, and instructional practices of teachers in teaching and learning as a whole. A programme that takes teaching and learning as an intertwined process and aims to develop teachers as a community of active learners would be more promising for the preparation of competent field PBL practitioners.

7.3 *Empowering Students to Share the Facilitator's Role*

The new FBL process requires students to meet in small groups, at least once, to discuss the problem and design their investigation plan. It requires the subject teachers to divide the class into a number of groups, with five to seven students to necessitate group discussions prior to the on-site activities. Given the large class size (up to 36–40) in most schools, potential conflicts in priorities can arise when there are not sufficient teachers with complete knowledge of the process. For wider practice in schools, there is a need to train up students to be the group facilitators. In fact in some of our workshops, we overcame this caveat by training senior students to become PBL facilitators for the junior classes.

7.4 Prior Preparation and Follow-Up Work with the Students

Since the majority of the students are accustomed to traditional learning approaches, it is essential for them to psychologically get prepared for the new approach. Teachers should communicate with students about the new approach to learning, expectations, and assessment criteria. For the weaker classes, it is useful to develop some essential learning strategies for students before the actual PBL is implemented. This helps students to tune in quickly and to maintain a high level of interaction. After the FBL, it is also critical to arrange debriefing sessions for the students to evaluate and reflect on their learning process, products, and to set new goals as a kind of metacognitive development.

8 Conclusion

This chapter introduces how field PBL can be adopted to enhance the effectiveness of FBL. Since the project described here was developmental and exploratory, it was not designed to determine definitively if field PBL participants (both teachers and students) outperformed those who adopted conventional field instructions. While the direct feedbacks from participants and schools may be indicative of the new approach's effectiveness to some extent, still it is practically impossible to attribute any difference in participants' performance to a particular variable. For such kind of large-scale development programmes, precise evaluation, particularly control experiments, is difficult to administer and to measure the changes that take place for every participant. Nevertheless, the data we collected from different sources confirmed that both teachers and students were benefited from this new approach.

The project was theoretically and practically significant in the sense that it introduced a new practical model in FBL. At the same time, it opened up new lines of research in both FBL and PBL. There were a few small-scale studies conducted by school teachers after they had received the teacher development programmes. For a clearer picture of the field PBL effects, future research should focus on the systematic evaluation of students' changes in their conceptions and approaches to learning, as well as their actual performance under this new curriculum and instructional system. In addition, it is essential to examine how changes in students' learning process help to change and sustain teachers' beliefs and practices in FBL.

Overview

Background and Motivation

- The new academic curriculum in Hong Kong has called for educators' conviction in shifting from merely imparting students with subject contents to developing students' ability to sustain lifelong learning.
- FBL enables students to understand concepts through illustrations with real samples and develop an appreciation of the complexities of real-life cases.
- While FBL can be regarded as a total approach to education, still its merits are often not fully exercised as many teachers still conduct field trips in a teacher-centred or solution-oriented manner.

Innovations and Findings

- The field-learning approach developed in this study essentially amalgamates PBL with FBL.
- The field-based workshops in this government-funded project required students to analyse a problem statement, formulate study problems, and devise own investigation plans based on the problem statement, with teachers resorting to the role of the facilitator and assessor.
- The PBL approach provides an alternative pedagogy of conducting student FBL, engaging students in the learning process, and requiring students to manage their own field trip programme.

Implications for Wider Practice

- The PBL approach is ideally suited for managing independent enquiry study, a mandatory component in the new secondary curriculum in Hong Kong.
- Since the new approach does not require subject-specific expertise on the part of the teacher, teachers from different disciplines can organise and supervise competently student field studies.
- The project highlights the possible adoption of PBL pedagogy in secondary school curriculum.

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Part III
Online Approaches

From Local to EXtreme Environments (FLEXE): Connecting Students and Scientists in Online Forums

William S. Carlsen, Liz Goehring, and Steven C. Kerlin

1 Introduction

Science education reform efforts in recent years have called for a "new way of teaching and learning about science that reflects how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world" (NRC 1996, p. ix). Scientists and engineers, experts in scientific practice, have been called upon to help model these practices for students and to demonstrate scientific habits of mind. The science education research literature includes a number of rich, project-specific descriptions of beneficial outcomes when scientists and students work together (e.g., Hsu and Roth 2010; Rahm et al. 2003; Rock and Lauten 1996). Questions abound, however, concerning how best to involve experts, given the very real challenges of limited availability of scientists, varying experience with effective pedagogy, widespread geographic distribution of schools, and the sheer numbers of students potentially involved. Technology offers partial solutions to support some student-scientist interactions (SSIs). Our international environmental education project has developed online forums to support SSIs, making use of web and database technology to facilitate communication between students and scientists (Kerlin et al. 2009). We approach questions of design and efficacy scientifically, including the use of randomized trials, explicitly testing the effects of SSIs on student learning and attitudes toward science.

W.S. Carlsen (✉)
Department of Curriculum and Instruction, The Pennsylvania State University, University Park, PA, USA
e-mail: wsc10@psu.edu

L. Goehring
Department of Education & Public Engagement, NEON, Inc., Boulder, CO, USA

S.C. Kerlin
Wisconsin Center for Environmental Education, University of Wisconsin – Stevens Point, Stevens Point, WI, USA

V.C.H. Tong (ed.), *Geoscience Research and Outreach: Schools and Public Engagement*, Innovations in Science Education and Technology 21, DOI 10.1007/978-94-007-6943-4_6,

Forums in our project are designed to showcase scientific practices and habits of mind through facilitated interactions between students and scientists. Through these online forums, students "meet" working scientists and learn about their research and the environments in which they work. Scientists provide students with intriguing real-life datasets and challenge students to analyze and interpret data through guiding questions. Students submit their analyses through the forum, and scientists provide feedback and connect key concepts and instructional activities with real-life scientific practices, showcasing their activities in the field. Forums are embedded within inquiry-based instructional units focused on essential learning concepts and feature the deep-sea environment in contrast to students' local environments, in order to strengthen students' understanding of earth systems processes.

2 Context

FLEXE is the NSF-funded project, "From Local to EXtreme Environments: Deepening Earth Systems Science Understanding with GLOBE" (NSF #0627909, Directorate for Geosciences). FLEXE is a collaboration among GLOBE, the NSF-funded Ridge 2000 research community, and researchers from Penn State University. GLOBE (Global Learning and Observations to Benefit the Environment) is an international environmental education program that engages teachers and students in investigations of diverse local environments. Ridge 2000 facilitates the interdisciplinary research of an national network of scientists that studies deep-ocean hydrothermal vents, where geological and biological systems are unusual (e.g., in these settings, chemosynthesis is the basis of the food web). The FLEXE project has used the GLOBE and Ridge 2000 networks to connect teachers and students from six different countries (USA, Australia, Costa Rica, England, Germany, and Thailand) with deep-sea scientists in studies of local and remote environments.

In FLEXE, middle-school-age students investigate a familiar terrestrial environment and compare their findings to data from both a partner school (elsewhere in the world) and a deep-ocean site. To date, more than 3,500 students have participated in FLEXE projects. Each project entails 20–25 days of lessons, including fieldwork, laboratory activities, other classroom instruction, and work on computers.

FLEXE projects include some student activities that are common in contemporary science instruction:

- Teacher-directed instruction
- Protocol-driven laboratory and field investigations
- Small group work to analyze data and reach conclusions

And some that are fairly unusual:

- Comparison of local data with data collected by students elsewhere in the world and with data collected by scientists, through structured, web-based interactions
- Peer review of research findings from fellow students and response to peer feedback

- Communication with scientists, through responses to questions that direct students to compare terrestrial environmental investigations with research in deep-ocean settings

We have developed and implemented two instructional projects: one focusing on the flow of energy and one on ecology.

3 The Energy Project

The first project developed by FLEXE focused on energy transfer in terrestrial and deep-ocean environments. Students completed a number of learning activities, including a web-based multisite comparison of seasonal and diurnal temperature variation, examination of deep-sea extreme temperature patterns, and an empirical study of temperature variation in students' own schoolyards. The latter activity culminated with student submission of research reports, followed by web-based peer review of reports that involved students at schools elsewhere in the world. Students also read narratives about deep-sea research, viewed slideshows and video clips from the deep-ocean setting, and participated in four interactive FLEXE forums, designed to facilitate student-scientist interactions (SSIs, discussed below). Several project activities, including webcast phone calls and ship logs, were carried out during Ridge 2000 research cruises and involved shipboard scientists and other ship personnel.

The Energy Project was piloted twice: first in 2007–2008 with several hundred US students and second, with additional activities and both US and non-US students, in 2008–2009. The 2008–2009 project involved 1,419 students and 47 teachers. Teachers were recruited with the assistance of the GLOBE Program and received training through Adobe Connect sessions and on-site workshops that we offered in the teachers' countries.

Analysis of student outcomes in this phase included the systematic comparison of students' written arguments as a function of their placement in one of two randomly assigned treatment groups: one in which American science classrooms were partnered with other American classrooms (the "domestic" treatment) and one in which they were partnered with classrooms from elsewhere in the world (the "international" treatment). Students submitted and received peer feedback within these treatment groups, and forum activities (discussed below) required students to compare their local data to data from their partner school, as well as to data from the deep-sea environment. Content analysis of students' written work included both broad exploratory data analysis of the use of a wide range of "evidentiary argumentation components" in a sample of student responses and multi-coder analysis of down-selected components using a separate set of 661 written arguments (responses to one of the forums). This two-stage process disclosed several modest advantages of the international treatment, including better outcomes in written student-student interactions (Kerlin 2009) and student-scientist interactions (Kerlin et al. 2011). Specifically, in their written arguments, students in the international treatment wrote

Fig. 1 Screen shot of a student's view of a FLEXE student-scientist forum. This and other pages can be explored at http://www.flexe.psu.edu/main/Ecology_unit.cfm

a higher percentage of correct scientific claims, provided more evidence to back those claims, and more commonly used some specific argument strategies, such as the presentation of quantitative comparisons. The advantages of the international treatment appear to include both audience effects (related to the rhetorical challenge of communicating with students from another country) and data effects (the analytical challenge of comparing climate data with not just the deep ocean but also another terrestrial site, which might be, e.g., in another hemisphere).

Energy Project forums: There were four student-scientist forums in the Energy Project: (1) a water column temperature profile study with Dr. Matt Smith (University of Florida), (2) a longitudinal vent fluid temperature investigation that included volcanic anomalies with Dr. Karen Von Damm (University of New Hampshire) and Dr. Margaret Tivey (Woods Hole Oceanographic Institution), (3) a mid-Atlantic-vent plume "elevator ride" with Dr. Peter Rona (Rutgers University), and (4) an analysis of East Pacific Ridge faunal spatial distribution as a function of temperature with Dr. Chuck Fisher (Penn State University).

The Energy Project forums used a common format. A media-rich website introduced the scientist and his or her research in an engaging and human fashion (see Fig. 1), with the goal of interesting students in both the scientist and his or her research, a task made easier through the selection of research led by diverse, personable individuals who have interest in public outreach. Each forum website included a set of oceanographic data for students and a clearly described analysis task, broken down into developmentally appropriate steps. Depending on the forum, data were textual, quantitative, spatial, graphical, and/or photographic. For example, the faunal distribution forum dataset (#4 above) included high-resolution photographs of complex seafloor communities, with image tags showing species identifications and spot temperature measurements.

Using the scientist-provided datasets, students worked in pairs to analyze data and respond to a series of questions provided on printed worksheets; then, under their teachers' direction, they logged onto the FLEXE website and sent responses to the scientists. All of these steps were completed asynchronously within a time frame that was intended to balance teacher curricular flexibility, scientist availability (to review student answers and provide feedback), and the need for timely feedback to students.

After student responses were posted to the forums, FLEXE program staff worked with scientists to prepare scientist feedback to students, delivered through a lengthy follow-up web page. This feedback included both general responses to student ideas and numerous attributed classroom-level responses, such as "It is important to know if we are seeing something unique to one area or a general pattern. Kudos to students at the Nimitz School in Texas, who also suggested looking for similar patterns in other places in the ocean!" The preparation of this feedback involved collaboration between FLEXE staff and collaborating scientists, both to ensure that feedback was appropriate for an international middle school audience and to save time for the scientists, who were usually juggling other demands, especially when forums occurred during cruises.

Evaluative feedback to us from teachers and students in the Energy Project included students' written work, students' responses to formative evaluation questions (both subject-matter related and attitudinal) that accompanied each online activity, and follow-up surveys and telephone interviews with teachers by our external evaluator, Dr. Nancy Trautmann of Cornell University. Students eagerly anticipated each scientist's responses to their work, even when the responses were attributable to only the classroom level (because of human subjects considerations, although we tracked student responses via anonymous user names, only the classroom teachers could associate those user names with actual students). In fact, "reading scientists' responses to student questions" was annually reported by teachers as one of the most significant project components in contributing to student engagement and motivation. For this reason, we decided to look more systematically at the role of personalized scientist feedback in the next FLEXE project.

4 The Ecology Project

The second FLEXE project combined ongoing attention to the physical conditions of geologically "extreme environments" (with respect to temperature, pressure, and the presence of naturally occurring toxic chemicals, all characteristic of mantle-spreading zones and hydrocarbon seeps) with education about ecological research.

In this project, the objective was to help students deepen their observation skills and develop testable research investigations in their local environment by introducing students to ecological research in "extreme" environments. Through new instructional activities and a series of forums that featured novel datasets coupled with ongoing communications with scientists, we challenged students to consider the relationship between geochemical processes, abiotic factors, and the organisms that live in unfamiliar settings and then apply what they learn to their local, familiar environment. Ecological concepts explored in this project included animal distribution patterns, primary productivity through photosynthesis vs. chemosynthesis, symbiosis, evolutionary adaptation, trophic relationships, succession, and biodiversity.

Having previously established—at least for our needs—the better outcomes of the international treatment in student communicative partnerships, we turned our research attention in the Ecology Project to a different question. For the 2009–2010 Ecology Project, we randomly assigned all participating classrooms to one of two treatments: a "personalized scientist feedback" treatment and a "non-personalized feedback" treatment. Students in the latter treatment would receive scientist feedback that was substantively identical to the personalized feedback, but without references to the work of students in specific classrooms. Our objective with this comparison was to evaluate the feasibility of running future FLEXE projects in an "archived mode," that is, not in conjunction with concurrent Ridge 2000 research cruises and live scientist feedback.

Ecology Project forums: There were three forums in the 2009–2010 Ecology Project, which engaged more than 1,100 students and 43 teachers worldwide. The subject matter of the three forums concerned methods of spatial ecological research, adaptation and symbiosis, and biodiversity. The mechanics of the forums were similar to those of the Energy Project, with the one difference being the varied nature of the scientist feedback.

To compare the effects of personalized and non-personalized scientist feedback, some 4,198 student responses to forum questions were content analyzed. Two dimensions of responses that were systematically assessed were *response focus* (the extent to which the student addressed the scientist's question) and *response accuracy* (the extent to which the response was scientifically justifiable, given the data provided by the scientist and data provided at the school level). When the responses to all three forums were combined (in order to maximize statistical power), a statistically significant advantage was observed for the personalized treatment over the non-personalized treatment for both response focus and response accuracy (Petersen-Pereira 2011).[1] The personalization of scientist feedback appeared to make a difference in motivating students *and* in the quality of the work that they submitted to our forums.

[1]Given international variation in school calendars and other factors, teachers were not always able to have their students submit their forum responses within the project time frame. When a classroom posted its forum responses after the deadline, those responses were excluded from the above-described analysis. As a result, we have entire classrooms of missing data for each of the forums, and those holes in our dataset obviously interact strongly with "teacher/classroom," which is usually a strong predictor of outcomes in educational research—often stronger than the treatment effect. Isolating the effects of treatment, forum, teacher/classroom, and their interactions is a complicated statistical story that we are still unraveling.

5 Implications for Practice

Projects that involve student-scientist interactions have implicit challenges. The first is how to engage scientists effectively. The Ridge 2000 community of scientists has a 30-year history of sharing amazing discoveries made at mid-ocean ridge environments with public audiences (Goehring et al. 2012), including several projects that have specifically targeted teachers and students (e.g., the REVEL Teacher at Sea program, the Dive and Discover expedition website, the Extreme 2000 website series, and the Student Experiments At Sea project). Collectively, these efforts established that ship-to-shore communication with schools can provide web-based access to scientists at sea and to the deep-sea environment, which is very engaging for students. Many of the researchers involved have reported great personal satisfaction gained through their experiences with these projects, often as a result of the reflected enthusiasm of participating students and teachers. However, unless educational projects address classroom issues such as integration with educational standards or target appropriate levels of understanding, these projects are not useful to most classrooms of today (Goehring et al. 2005). Research scientists are not necessarily knowledgeable about precollege pedagogy. Effective scientist engagement in education means focusing the project on addressing students' needs, such as understanding the larger context within which research findings fall and developing scientific thinking skills. In FLEXE, we developed materials through collaboration between scientists and educational experts.

A second challenge concerns scalability. Scientists are busy people whose participation in K-12 outreach is usually secondary to their other duties, like research and teaching. As a project grows from a handful of students to hundreds or thousands, *scientist time* is inevitably a limiting resource. Again, we addressed this in part by employing education professionals to read through student responses, assessing their understanding as well as misconceptions, and helping write appropriate responses. To facilitate the review of so many student writings, we developed database tools to allow scoring and sorting and annotation of student responses.

As a possible next step, we have storyboarded, but not yet tested, database tools that engage participating teachers in the down-select of student work, for closer scrutiny by scientists. The idea is that after students respond to a scientist's question posed on an online forum, teachers would have the option to review their own students' responses and flag responses that are representative, interesting, or otherwise worthy of further scrutiny. The task at our end would thus be reduced from sifting through thousands of responses (a large number of which may be very similar) to reviewing a much smaller number that have been pre-filtered by teachers. This could be an effective way to both down-select and involve teachers in a meaningful way, with minimal overhead. Yes, it would effectively shift some of our work to the teachers, but our experience in FLEXE has been that effective teachers do this kind of preliminary review anyway, as part of their routine evaluation of student work. More importantly, the limited resource of scientist time could now be used more efficiently. It is less likely that an especially insightful student idea would be overlooked.

A third challenge concerns the need for educational infrastructure. The oceanographic research carried out by Ridge 2000 could not be done if its individual funded scientific projects had to locate, schedule, provision, and operate their own ocean-going research vessels, satellite communication systems, submersibles, and so on. We suggest that a similar shared-services philosophy is worth considering for educational outreach operations, especially for projects that engage scientific networks. The web-based forum tool that we developed may be useful to other scientific outreach initiatives, and, in fact, we are currently working closely with the principals of another NSF earth systems science education project to evaluate its use there (Jona et al. 2006). After that, the future of the tool is uncertain; it may become a ship without a scheduled cruise. How an educational infrastructure for outreach would be funded is one of many questions that would need to be considered, but it is inarguably inefficient that so many outreach operations associated with scientific research literally start from scratch in building methods for connecting scientists and schools.

Overview

Status Quo and/or Trends

- There is substantial contemporary interest in involving scientists in outreach to schools.
- Outreach by scientists and engineers can help K-12 students understand that science is more than a static body of established facts; science can be dynamic, social, creative, and exploratory.
- Progress in many scientific domains benefits from international collaboration.

Challenges to Overcome

- Scientists have incomplete knowledge about the needs of schools and, realistically, have limited time to understand and respond to those needs, even when they would like to do so.
- Effective science-school outreach demands active translation and accommodation between systems that are different in fundamental ways.
- Educational outreach efforts from science projects tend to reinvent the wheel; they rarely build from prior experience, in part because there are only scant opportunities to learn from that prior experience.

Recommendations for Good Practice

- Program evaluation should do more than document the effectiveness of discrete program; it should contribute scientifically sound recommendations for future interventions.
- Strategies for engaging scientists in outreach need to be realistic and use their time strategically and wisely.
- We should consider significant investment in educational infrastructure to support outreach efforts from future science projects.

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Communicating Scientific Research Through the Web and Social Media: Experience of the United Nations University with the Our World 2.0 Web Magazine

Brendan F.D. Barrett, Mark Notaras, and Carol Smith

1 Introduction

Researchers at the United Nations University (a global network of institutes with its headquarters in Tokyo) are encouraged to publish their research outcomes in peer-reviewed journals, working papers, book chapters and policy briefs. This is generally in line with standard academic practice, whereby contribution is measured in terms of number of articles in top-tier journals and the number of citations.

From 2008 onwards, the UN University began to explore how best to take advantage of the web to communicate research to a broader segment of society beyond academic and scientific peers. An online magazine called Our World 2.0 was launched that encourages UN University researchers to publish journalistic articles about their work. The magazine also accepts articles from non-UN University staff. Various social media (Facebook, Twitter, YouTube, etc.) are used to try to connect with a community of people interested in the work of the UN University.

Gaining support from researchers and persuading them to contribute articles have proven to be a major challenge for the Our World 2.0 editorial team. Some researchers have indicated that publishing an article online does not improve their career prospects or help them to attain tenure in the future after they leave the UN University. Others, while interested, have struggled to adjust their style of writing to a less academic form and have required a fair amount of editorial support. A third group has been willing to contribute but has been less than convinced about the value of social media. This is not unexpected. In spite of the fact that recent studies show that researchers are increasingly using social media when undertaking their

B.F.D. Barrett (✉) • M. Notaras • C. Smith
Office of Communications, United Nations University, Tokyo, Japan
e-mail: barrett@unu.edu

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research activities, many academics remain cynical about the use of Facebook, Twitter and YouTube as a means to disseminate their research findings (University College London 2010).

Nevertheless, the majority of UN University researchers who have contributed to Our World 2.0 have been delighted either to see their work picked up on partner websites/blogs or to see how many people commented on their articles.

This chapter provides background information on the Our World 2.0 online magazine and shares insights that have been gained over the past 4 years with respect to research dissemination opportunities afforded by the World Wide Web and social media.

2 Social Media and Web Trends

It is clear that the landscape of scientific research communication is being transformed as the web alters how we interact and engage with online information. With an estimated two billion people now online and with web penetration reaching as high as 78 % of the population in North America and nearly 60 % in Europe,[1] it is the web that is driving our communications and knowledge exchange activities more than any other form of media (overtaking television recently according to the Digital Life survey by TNS).[2] The rapid rise in social media[3] and the dramatic growth in the production and sharing of video via YouTube are just two facets of the change under way. For instance, it was recently estimated that the world collectively spends nearly three billion hours on YouTube each month, with the average user spending 25 min on the site per visit.[4] Increasingly these visits have an educational role, as well as entertainment value, with more and more universities publishing videos on YouTube.

There may be a generational gap at play with these new opportunities to access content via the web primarily appealing to the so-called digital natives (Prensky 2001). Digital natives are those who have grown up with digital technology and spent their entire lives using it. They have come to expect instant access to the information they need via the web. They are at the forefront of an ongoing transformative process characterised by a new connectedness within our modern way of life. This transformation is something that the scientific and research community cannot ignore if it is to remain relevant. It is true that for certain geoscience topics, especially in very technical fields, researchers will continue to share what they have learned with their colleagues and institutions through peer-reviewed scientific journals.

[1] Data as available for March 31, 2011, and accessed at http://www.internetworldstats.com/stats.htm

[2] To access the Digital Life Survey data, see http://discoverdigitallife.com/the-digital-landscape/

[3] Facebook was launched in February 2004 and now has over 750 million members. See https://www.facebook.com/press/info.php?timeline

[4] For more statistics, see http://royal.pingdom.com/2011/02/04/facebook-youtube-our-collective-time-sinks-stats/

In relation to pressing global issues like climate change, however, if scientists publish only in peer-reviewed journals and remain disengaged from the places where everybody else is connecting, it may prove difficult to ensure that research outcomes are effectively communicated to broader society. The point here is to encourage scientists to engage with the public via other channels and not to limit themselves to journals.

This situation is compounded even further if academic publishers continue to restrict access to scientific knowledge to those with the ability to pay.[5] While the purpose of restricted-access, peer-reviewed journals is to ensure scientific quality and to communicate more technically oriented research outcomes to peers, the goal of open access, web-based dissemination is to encourage widespread public debate and to increase the speed of research feedback. Both are valid roles and can coexist effectively. However, one should not be allowed to undermine the other.

3 Challenges to Overcome

The advantage of the web compared with communications channels like television or the printed news media is that there is no gate-keeping editor deciding what you may or may not find interesting. Moreover, if the principles of open access publishing are followed online, then there is a tremendous opportunity to share the outcomes of scientific research more extensively across society. However two important obstacles need to be overcome.

First, when information is flowing freely, as we find on the web, your information has to compete with everything else. For the online audience, if the information is poorly presented, it will quickly slip into the "boring" or "to be ignored" category. Second, if you accept the principles of open access, as an online publisher, then you also have to give up a measure of control of your research materials as afforded by intellectual property rights and copyright. In other words, you may want others to copy and share your work, but you will have to accept that you may not be able to completely control how they do so.

We have just begun to see universities getting to grips with these challenges so as to share their research and expertise via the web in new and engaging ways. A good example is Environment 360 (http://e360.yale.edu/), an online magazine from the Yale School of Forestry and Environmental Studies. The magazine, launched in 2008, features articles by "scientists, journalists, environmentalists, academics, policymakers and business people, as well as multimedia content and a daily digest of major environmental news". It is supported by an online community on both Facebook and Twitter and via reader comments on articles.

It is coincidental that the UN University launched Our World 2.0 in July 2008. This online bilingual (English/Japanese) magazine explores the complex interactions

[5] See George Monbiot, The Lairds of Learning, accessible at http://www.monbiot.com/2011/08/29/the-lairds-of-learning/

between climate change, peak oil, biodiversity and food security. While the magazine is environment focused, our contributors seek to address challenges that intimately affect people from all four corners of the planet. So, for instance, efforts to ameliorate the advent of peak oil through the adoption of biofuels in Europe or the USA can impact the food security of communities in the Global South, if poorly implemented. International organisations like the UN University are well placed to articulate these interconnected issues from a truly global perspective and to share credible scientific knowledge with citizens.

As previously mentioned, since its establishment by the UN General Assembly in 1972, the UN University has generally disseminated its work via edited volumes, many published through the UN University Press, and articles in academic journals. The result is that the audience for the UN University's research has generally been technical, policy oriented or academic. The Charter of the UN University is very specific, however, in terms of the role that the institution could play. It states that the "University shall disseminate the knowledge gained in its activities to the United Nations and its agencies, to scholars and to the public, in order to increase dynamic interaction in the world-wide community of learning and research". The key term here is "dynamic interaction", and it is important to recall that this notion in the Charter predates the arrival of the World Wide Web and originally referred to the idea of bringing people together in training programmes, workshops and symposia. In essence, the truth may be that with the advent of the web, the full potential emerged to pursue this dynamic interaction globally. However, to do this required reconsideration by the UN University of how best to interact beyond its traditional constituencies.

Academic books are rarely bestsellers (although some academics do write to a broader audience and are outstandingly successful) with average sales per book of around 1,000–2,000 copies. Interestingly, Google Scholar is emerging as a new tool to evaluate the impact of academic outputs. For instance, Charles Darwin's *On the Origin of Species* has been cited over 23,000 times since 1978 and its impact is undeniable. Taking the example of two contemporary scholars we can see that *Being Digital* by Nicholas Negroponte (founder of the MIT Media Lab) has nearly 3,400 citations and *Code and Other Laws of Cyberspace* from Lawrence Lessig has been cited 2,380 times. The latter two works exemplify extraordinary modern academics who cross over to the public world to more effectively spread their knowledge. Negroponte, who set up Wired magazine, is a recognised commentator on all things digital and is also the founder of the "One Laptop per Child" initiative. Lessig is widely known for his efforts to free up content from copyright restrictions through the introduction of Creative Commons licences that lets the user decide which rights to reserve.

Anne-Wil Harzing argues that "good citation metrics show that a researcher has made a significant impact in the field".[6] For most academics, having their works

[6]See "Google Scholar—a new data source for citation analysis", A Harzing, http://www.harzing.com/pop_gs.htm

cited in the hundreds is a measure of real success, sufficient to attain tenure perhaps. For instance, one of the most cited books from the UN University is Robert Ayres' 1994 work *Industrial Metabolism: Restructuring for Sustainable Development* with over 400 citations. For the majority of scholars, we console ourselves with the thought that we are perhaps big fishes in small research ponds covering very specialised topics, so the potential to be cited is likewise small.

With the advent of the web, the UN University, like other universities, early on embraced the communication possibilities on offer, in what can be primarily understood as Web 1.0. Put simply, the initial stage of the web was characterised by static web pages, pushing content to passive readers mainly describing "who we are and what we do". While the UN University has engaged with Web 2.0 at various institutional websites, it was only through Our World 2.0 (as implied by the name) that a conscious effort was made to incorporate the main features of Web 2.0 in an experimental and innovative manner. Web 2.0 includes a "strong social component" through user-generated content such as comments, tags and ratings (Cormode and Krishnamurthy 2008). For Our World 2.0, the basic idea was to ask UN University researchers to repackage their research in a form that is more accessible to the public at large by writing in a more journalistic style, keeping the message short, sharp and simple. The researchers are requested to avoid acronyms, colloquialisms, as well as academic and scientific jargon. Writing for Our World 2.0 adds value to the UN University's traditional modes of disseminating research findings; where possible, policy briefs and technical working briefs accompany Our World 2.0 articles as downloadable PDFs for those interested in reading further.

At the time of writing, a total of 644 articles have been published in English and Japanese. The main form of interaction with the Our World 2.0 community of readers has been through the comments section associated with each article, and to date, there have been 2,387 comments. It is important to recognise here that this was the first time that anyone online could comment on the research of the UN University. The publication of each article is normally accompanied by a message on Twitter (the magazine's Twitter identity has 6,332 followers) and on Facebook (5,500 followers). The readership of Our World 2.0 is in the order of half a million unique visitors each year, making it the second most visited website within the UN University network after the main site of the university. This demographic data, derived using Google Analytics, indicates which countries the readership comes from, how long they spend on site and which articles are most popular (i.e., most frequently viewed). The data is supported by online reader surveys that provide additional information on the age, gender and educational/professional background of the readers. The demographic and survey data is primarily used by the editorial team to guide the selection of articles for publication that are considered likely to be of interest to the readership.

From the beginning, video was viewed as a central component of the research communication activities for Our World 2.0 with an emphasis on the production of short 5–10-min videos by an in-house production team. The videos are posted in the magazine and on YouTube. Individual researchers have begun to incorporate the videos in their teaching materials and dissemination activities. One colleague shared the following e-mail message with the Our World 2.0 team, showing how the videos are utilised:

> We have put together an article to go with the three videos that were produced recently. Although they are being used by other agencies on their sites, perhaps it would be good to combine the videos and article on the main UN University site, as a summation of the Tokyo assessment workshop, as well as the conclusion recently of the first plenary meeting in Nairobi.

Since the videos are accessible via YouTube, other partner institutions can easily embed them on their own website. YouTube has proven to be a very effective communications channel with over 4.4 million views of the videos and over 3,200 subscribers. Still, by YouTube standards, this level of viewership is relatively modest (for instance, Prof. Michael Wensch at Kansas State University had over 11 million views for his video on "Web 2.0…The Machine is Us/ing Us") but nevertheless compares favourably with the 7.2 million views for videos on UNESCO's YouTube Channel as of June 2013.

4 Concerns for a New Communication Realm

One point to highlight here with respect to the development of Our World 2.0 is the importance of high-quality web design as a means to enhance communication. Much effort has gone into the design of the online interface to try to engage and retain the reader's attention. This includes the careful selection of banner photos, the presentation of an extensive list of articles with thumbnails and the easy access to social media and featured content. The design, branding and visual communications around the magazine are arguably as important as the substance of the articles. The same applies for the titles of the articles. UN University researchers have a habit of choosing very long titles for their papers that are not compatible with the expectations of people consuming web content, even if they are supremely interested in the issues. To deal with this, only limited space is allowed for the title and the authors need to use it and the opening paragraphs of articles creatively to convey their central message. Behind the scenes, a similar problem occurs in how the article is tagged with keywords in the "back end" content management system to ensure that it is easily found and catalogued by search engines. There is a whole science involved with search engine optimisation (SEO) that can work to ensure that your content appears at the top of the list when someone searches on Google, Bing or any other search engine. The reality is that if you do not seriously consider and design appropriate SEO strategies, you could end up on page 2 or 3 of search results and fewer readers will find your work.

A key component of the experimental approach underpinning the Our World 2.0 online magazine has been the adoption of Creative Commons licences for articles and videos. Creative Commons (http://creativecommons.org/) is a legally binding system of copyright that allows the creator of the content to decide what restrictions she or he wants to place on the content, rather than the default "All Rights Reserved". In the case of Our World 2.0, the UN University adopts the licence that requires attribution while permitting use for non-commercial purposes and under the condition that the user agrees to "share alike". The consequence of adopting this licensing scheme is that other websites, blogs and news sites are able to re-publish Our World 2.0 articles without asking for permission, as long as they comply with the terms of the copyright. The result has been the extensive syndication of Our World 2.0 in a number of environment-related websites such as the Energy Bulletin (http://www.energybulletin.net), Solutions (http://www.thesolutionsjournal.com/) and in the Guardian (http://www.guardian.co.uk/environment/series/guardian-environment-network).[7]

The adoption of the Creative Commons licence has the potential of greatly increasing the audience for the research outputs of the UN University beyond those who visit Our World 2.0. This is also true of the video briefs that have been produced for Our World 2.0 where we find them embedded in news items written for the Huffington Post, Treehugger and on Current TV. One video produced for Our World 2.0, which looked at a machine to convert plastic back into oil, received nearly 2.9 million views on the UN University YouTube Channel and another 721,000 views on another individual channel (i.e., some people copy videos to their own channel on YouTube, since it is permitted by the licence). We recently discovered that someone has created a Portuguese version of the video that has received over 22,000 views.

With social media, a great deal of information is available on your readership via their detailed profiles. This information helps to identify whether you are reaching individuals in academia, business, policy-making or someone with just a regular interest in your writing. There are tools that enable you to measure your relative influence online such as Klout (http://klout.com) that give your Twitter account a score measuring how many people you influence. At the time of writing, the Klout score of Our World 2.0 was 60 (out of 100) and the profile was one of "specialist" information source on topics such as environment, energy and economics.

5 Other Challenges

As mentioned previously, a key concern often expressed by UN University faculty members is that publishing via Our World 2.0 would not be acknowledged as a work of academic merit within the measurement scales normally used by universities when evaluating performance of faculty or the suitability of candidates for positions. In effect, the only real measure of academic output is through peer-reviewed journals. However, publishing a related article in Our World 2.0 has the potential to increase the readership of the original peer-reviewed paper.

[7] The UN University has a formal agreement with the Guardian online whereby it is possible, if both parties so wish, to exchange up to two articles each month.

A second concern that is often raised in discussions between the Our World 2.0 editorial team and researchers is one of quality. Essentially, submitting to a peer-reviewed journal ensures that the quality of the article receives some kind of formal recognition. While leaving aside the fact that the peer-review process itself has many detractors (Henderson 2010), the approach adopted for Our World 2.0 is that every article would be subject to editorial review by two to three editors. Admittedly, this is a less robust mechanism than most journals and inevitably there are challenges, particularly in rather technical fields where specialist knowledge is required. Nevertheless, it is one effective way to ensure quality and is supported by the fact that any errors with an article will also be identified by the readership, requiring immediate correction. In this respect, Our World 2.0 functions along the lines of the news media, whereby the research articles are subjected to wider public scrutiny and frequently aggressive and unconstructive critique/feedback. Some researchers find this situation to be rather discomforting and prefer the somewhat cushioned conditions of peer review where greater time is available to review and revise works (i.e., embarrassing lapses can be avoided). Other researchers seem to relish the idea that they can get immediate feedback on their writings and view it as an opportunity to test and sharpen their ideas amongst interested but non-expert audiences.

A third challenge relates to the use of video or podcasts to communicate research. If your past academic career has focused on journal outputs, it may seem grossly inappropriate and somewhat belittling to have to use video as a means to communicate your work, especially via YouTube where your work has to compete with "cute kitten in a box" for attention. The experience from Our World 2.0 shows, for instance, that videos of a "talking head" or lecture format are not necessarily engaging, unless they cover exceptional educators such as Prof. Michael Sandel at Harvard University. Sandel's inspiring lectures on Justice (http://www.justiceharvard.org/) have proven to be very popular on YouTube with around 2.3 million views for each video.

By far the most successful videos on Our World 2.0 focus on character-driven stories that engage the viewers (attracting anything from 3,000 to 30,000 views per video). Many of these stories capture the work of UN University in the field and show how our researchers are not isolated in the proverbial ivory tower but are on the ground examining environmental and social conditions and coming up with solutions in collaboration with local scientists and/or communities. The response often encountered when sharing these videos with colleagues, however, is that they must be exceedingly expensive to make. While there is some truth to this assertion, with individual videos from remote field locations costing around US$25,000, others closer to home are exceedingly cost-effective when travel costs are low. The challenge and focus here should be on measuring the investment versus return in terms of impact and to compare that objectively with other relatively expensive dissemination options such as holding workshops and conferences on the other side of the globe and compiling publications such as edited volumes that are frequently released years after the research remains timely.

And it is here that we get to the crux of the matter because the fourth concern that is often raised is how it is really possible to measure impact? Who are the 2.6 million people who watched the UN University video brief on plastic to oil on YouTube?

Who are the half a million readers of Our World 2.0 each year? What is being achieved if someone follows Our World 2.0 on Facebook or Twitter? Surely it is more important if someone reads and even better cites your journal article because at least then you can say that the knowledge you generated was used and added to a greater body of research? The answer to the last question is yes, that is certainly an important indicator of research impact. But if we are talking about research influencing society, “the public” as the UN University’s and other charters often put it, then normally we look to achieve the broadest dissemination possible and that is usually via television, radio and newspapers. However, with the advent of the digitally connected age, the web is emerging as an intermediate solution and one that is available for all to use. If your research were picked up by the British Broadcasting Corporation, *The Times of India* or the *Le Monde*, for instance, then the automatic assumption would be that this is a positive result. But if your research were watched by two million YouTube viewers, you would be less sure because you are less clear on the identity of those who watch YouTube.

We would argue, however, that this perception is changing and, further, that the big difference the web offers is the possibility for your community to respond directly to you. In the traditional media, the readers can write back to the New York Times newspaper and contest a reported research finding. With the web, they can write directly to the researcher and to their institution. There can be, if so inclined, a conversation around the research, and it can even be held for all to see—in the comments section of the online article. That is not to say that the conversation will always be civil or that it would be easy to manage, but it is a possibility with the right design, philosophy and community-building strategy.

6 Conclusion

In education and research, much of the writing on the impacts and challenges of the web, social media and technology has focused on how learning can be transformed. The experience from Our World 2.0, as expounded above, illustrates that scientific research communication in geosciences is likewise being transformed, perhaps less visibly and at a slower pace. What is clear at present is that active engagement (rather than denial and rejection) with the potential of the web and social media in the realm of research communication offers an array of new opportunities. Nevertheless, the learning curve is steep, the path is fraught with difficulties and mistakes are frequent.

Peter Drucker in his book *The Ecological Vision*, (Drucker 2000) while not referring to the digital world, provided an interesting insight on the situation we currently face. He argued that “the important challenge in society, economics, politics, is to exploit the changes that have already occurred and to use them as opportunities. The important thing is to identify the future that has already happened”. The transition to the digital, connected world and the advent of social media is the future that has already happened. But it is a future that academia is struggling to adapt to and take advantage of.

Overview

Status Quo and/or Trends

– The web and social media are transforming research communications.
– Openness lies at the heart of the web since there are fewer gatekeepers compared with traditional media and the sharing of content is made easier via open licensing, such as Creative Commons.
– Some universities and researchers are embracing these new communications opportunities including the UN University.

Challenges to Overcome

– Researchers can be concerned about how their peers evaluate online publishing outside of academic journals.
– Issues of quality and editorial control remain to be resolved.
– The validity of communicating with new types of media such as video and podcasts is unclear to many academics.
– Researchers remain unclear about how to measure the impact of their work online and via social media.

Recommendations for Good Practices

– This is just the beginning of the transformation and there are no guide-books or manuals. The only way to navigate this transition is through direct engagement and learning by doing.
– It is important to be as transparent as possible about how impact is measured so that others may give feedback and help in how data is interpreted.
– The boundaries around intellectual property online are blurred, and this should be embraced through open content licensing like Creative Commons rather than resisted. The goal should be to enrich the public domain, rather than allow it to be commoditised and closed down.

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Marine Geosciences from a Different Perspective: "Edutainment" Video Clips by Pupils and Scientists

J. Dengg, S. Soria-Dengg, and S. Tiemann

Abbreviations

DFG	"Deutsche Forschungsgemeinschaft" (German Research Foundation)
NaT	"Naturwissenschaften und Technik" (Natural sciences and technology)
SFB	"Sonderforschungsbereich" (Collaborative research centre)

1 Introduction

At a first glance, geosciences seem to be a prime example for a field of modern science with a largely positive image in public: They combine high-tech applications with the image of "good old Earth explorers" like Darwin and Wegener, they provide breathtaking pictures from various corners of the planet, they are inherently interdisciplinary using a wide range of methods from physics to biology, and they are directly relevant to many people because geosciences study phenomena like earthquakes or climate change. Consequently, we frequently see documentations on television about the work of geoscientists, where they are portrayed as climbing volcanoes, simulating tsunamis in computer models, diving into the ocean in submersibles or riding into the eye of a hurricane in an airplane.

And yet, when faced with making a decision on a future career, pupils in many countries are not really aware of geosciences as an option. Often, they enrol for a "real" science subject instead (like physics, chemistry or biology). In part, this is

J. Dengg (✉) • S. Soria-Dengg
School Cooperations, GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
e-mail: jdengg@geomar.de

S. Tiemann
Freie Waldorfschule Kiel, Kiel, Germany

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due to the school curriculum, where geosciences usually do not appear at all or only as a brief period in geography class (Brooks 2010). Many pupils shy away from sciences altogether because they are considered “difficult” or “irrelevant” (European Commission 2004). This is not surprising, because school science is often presented in such a way that the excitement of actual research and its relevance for our lives fail to come across.

Thus, in many places, geoscientists have started initiatives to communicate their work and their topics directly to the public and in particular to schools. However, they are quickly faced with a dilemma: To go beyond the image of geosciences as merely a “soft” science and a great adventure, they need to emphasise state-of-the-art research, but they have to assume that their audience is not familiar with many of the concepts behind it. Or, even worse, they may be confronted with an audience of which a significant part is not really interested in sciences at all. Thus, a big challenge is to break the scientific message down into suitable portions and to present those in an attractive way.

In this article, a project is presented where researchers work jointly with schools in exploring new ways of communicating the concepts and the excitement of biogeochemical and geophysical research and the relevance of this work.

2 Motivation and Rationale

At GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, a programme for a close collaboration with partner schools has been in place since 2004: In “NaT-Working Marine Research” (NaT standing for natural sciences and technology), projects are defined and carried out jointly by ocean scientists, teachers and pupils from secondary schools. Project periods range from days to a whole school year, and individual pupils, groups or complete courses can participate (cf. NaT-Working Meeresforschung 2013). Disciplines cover all aspects of marine research including ocean physics, marine biology and chemistry, meteorology, geology and geophysics. The emphasis is on active work by the pupils on up-to-date science topics, usually involving experiments, sampling, literature research and discussion with the scientists. These activities are tied into the institute’s outreach concept, and their results are shown to the public at Open Days or other special occasions (Fig. 1).

Building on this background, and supported by the scientists of two major research consortia in Kiel (Collaborative Research Centres 574 and 754, both funded by DFG, the German Research Foundation), in 2008 GEOMAR’s school programme decided to initiate a project that adds a new and unique component. “Traditional” outreach work (press releases, web pages, etc.) was supplemented by the production of video clips to carry the science of the two research programmes into schools and to communicate its relevance to the public. To achieve this, a critical part of the target audience (i.e. the pupils themselves) was involved and contributes directly to the project.

However, communicating the background of the research topics of the two SFBs (short for “Sonderforschungsbereiche”, i.e. collaborative research centres)

Fig. 1 Pupils demonstrating their earthquake simulator to visitors during Open Day at GEOMAR

proves a formidable challenge: SFB 574, after 12 years now in its final phase of funding, deals with "Volatiles and Fluids in Subduction Zones" (cf. SFB 574 2013) and is mostly focused on geological and chemical aspects of plate tectonics. SFB 754 (presently starting its second 4-year phase) concentrates on "Climate-Biogeochemistry Interactions in the Tropical Ocean" (cf. SFB 754 2013) and investigates the physical, chemical and biological processes at work in oxygen minimum zones in the Pacific and Atlantic. Clearly, both science projects work on highly specialised questions at the cutting edge of research. The knowledge required for an appreciation of their new results often greatly surpasses high-school level and is completely beyond the horizon of the "average man on the street". The challenge thus is to concentrate on the background of this research and explain its relevance based on fundamental concepts that are easy to comprehend. Furthermore, ideally this has to be transported in a way that is also attractive to the young generation.

Thus, a new concept was introduced in the project "SFB Outreach": Mentored by the researchers and special staff, pupils from partner schools produce "YouTube-style" online video clips (Fig. 2) on particular aspects of the research topics. As contributions gradually accumulate, they add up to a video-mosaic that begins to portray the concepts behind the science. To be effective, the resulting video clips must be:

- Short (i.e. web-consumer-friendly with a length of about 5 min and focusing on only one particular scientific concept, such as oxygen isotope ratios in seawater under different climatic conditions)
- Original (these productions cannot hope to compete in quality with professional TV documentaries, and so they have to compensate by being funny, exciting or "cool" and, if possible, "addictive")
- Freely available (for download as teaching material in class or to be shown to friends)

Fig. 2 Video shooting during summer school programme

The primary target audience are the "producers" themselves: By forming small teams with a distribution of tasks (from scriptwriter to film editor), even pupils who would usually turn their back on sciences are personally brought into contact with research, technology and real scientists. Ideally, during this process, some of them will discover that science can be fascinating after all. Once the video clip is completed, it will carry this message also to their friends and other pupils.

However, as in most projects that try to attract pupils to sciences, it will be virtually impossible to quantify if this approach really manages to attract any new students to study geosciences at university. There are too many other factors that influence such a decision, and it is very hard to keep track of test persons over several years. For this among other reasons, a secondary effect is targeted at teachers. During the video production or by the video clips themselves, they are introduced to new research and new ways of presentation, and they may find that some of the ideas and materials can be used to enrich their science teaching.

Thirdly, the broader public can be reached through the products of these courses. To support this, the video clips and materials for school are made available online on a dedicated website (SFB Outreach 2013).

3 Implementation and Timeline

The key elements of SFB Outreach's concept are (1) the active participation of the pupils who are confronted with the challenge of understanding a particular science topic and who contribute their own style and language in communicating it to other pupils; (2) the involvement of ocean scientists who make sure that in an effort to create “cool” videos, scientific content is not sacrificed; and (3) the support by teachers, which is only readily given once they are convinced that this approach contributes to their teaching in a positive way.

Although positive signals from all these groups had been received when writing the proposal, when SFB Outreach was approved and funded by DFG in 2009, the potential contributors needed to be activated. To achieve this, a coordinator with a background in public outreach of science was recruited to act as a liaison between the research institute and the schools and to administrate the day-to-day affairs of the project. In consultation with professional video producers, five sets of video equipment were initially acquired, containing HD video cameras, microphones, media for data transfer and storage and computers for editing video footage. These materials are available for loan to schools and have been in almost continuous use since the start of the project. In several workshops, video professionals provided initial training on video production to the project’s staff.

In parallel, the first meetings with teachers were organised to introduce them to the idea of the project and to discuss the feasibility of conducting video projects on the topics of SFB research in their schools. Although several teachers had been quite open to this during the proposal stage, the concrete suggestion of starting a video project in their own class now encountered considerable reservations. Usually, these were related to the time frame of the project and/or the particular topics that could be accommodated in the curriculum. Some teachers also questioned whether “producing just another video clip” really has sufficient educational value. To bypass this, contacts were made to teachers who offer video activities as after-school projects. This, however, soon turned out to be a dead end because most of the pupils participating in video groups do so for artistic reasons and not for science.

On the other hand, some of the scientists doubted that pupils are capable of communicating their complex scientific topics. In particular, they questioned the pupils’ ability to narrow down individual aspects of their research to the required few minutes of online video while conserving the core message and embedding it into an appealing story line or design.

To overcome these difficulties, a small 2-day workshop for teachers and pupils was held together with scientists in January 2010. The first practical exercises quickly convinced all participants that the task at hand was manageable and indeed suitable for secondary schools. In the next months, the first experimental productions were carried out with small groups of pupils who happened to be participating in an internship programme at the research institute and volunteered for the video project. As a result of the first feedback by these pupils, modifications to the programme were made. Video-editing software for beginners was adopted instead of semi-professional products that proved to be too complex and resource demanding.

Eventually a routine developed in which the pupils (typically of age 15–19) first receive instructions on the handling of the video equipment, an introduction to the tools and methods of video editing and to the concept of a storyboard. Then, researchers introduce them to their science topics in one or several oral presentations, sometimes in combination with a visit to the laboratory and a look at their

Fig. 3 Pupils learn to take samples from a sediment core in the laboratory

instruments or samples. (In most video projects so far, these first steps take up about 2 days of the project). If more time is available, pupils are involved in practical work, e.g. by taking samples from a sediment core in the laboratory (Fig. 3), by setting up Winogradsky columns to study microbial ecology or by growing phytoplankton cultures in bottles on the windowsill.

If working with a complete class, the group is split up into production teams of 4–6 pupils. Each team has the task of creating its own story plot that places the science topic into a new context to approach it from an unexpected angle for better effect. Styles of presentation can be commercials, children's programmes, documentaries, music videos, short dramas, etc. To minimise the temptation for the scientists to impose their own preferences on the presentation, the storyboard is usually created independently by the pupils. However, at some point during this process, feedback from the researcher is important to discuss if an intended interpretation does justice to the science topic and to clarify emerging questions on the science. Typically, this stage of the production may take several hours or up to 1 day.

In the next step, the actual camera shooting takes place, involving the pupils as directors, sound and light technicians, prop designers, special effects supervisors or actors. (Note that – particularly for work with a complete class – these technical or artistic tasks are often ideal for pupils who are less inclined towards sciences). Once all scenes are done, the pupils concentrate on post-production (Fig. 4), i.e. the editing of the material, additional sound work, creation of titles and credits and selection of music. This aspect of the production takes up at least 2–3 days but should be allocated more time if possible.

The entire process described so far typically requires a minimum of 5–6 full workdays for the pupils. Frequently, this is also the maximum a school can afford to spend on a project. To sustain a common level of technical quality in the final

Fig. 4 Editing of the video clip

videos, however, additional post-production work is necessary. For this, the project team is supported by student assistants experienced in film editing. They are employed to back up and manage the increasing amounts of raw video footage, improve sound quality, shorten lengthy scenes, add credits and supply subtitles or graphics to improve comprehensibility if necessary.

4 Outcome of the Project

The work in SFB Outreach imposes a steep learning curve on everybody involved. The pupils are faced with two new areas of expertise that they have to cope with, i.e. the science itself and the techniques of video production. In spite of the pervasive presence of YouTube and video on computers and smartphones, know-how with respect to planning and carrying out a video project is not as widespread among pupils as one might assume. Fortunately, after initial scepticism, acceptance for this approach has grown among the teachers, pupils and scientists involved in the project.

In total, at this point (December 2011), there are 22 completed video clips (Fig. 5) available on the project's website (SFB Outreach 2013) and some more in the final stages of post-production. So far, two videos have not been published because of potential copyright issues and three due to insufficient quality. The clips vary in length between 4 and 8 min, and presently all of them are in German. (English subtitles or even productions completely in English are envisaged in the next stage of the project). After the first 3 months since the official start of the website in September 2011, the number of online views per video clip is 130 on average, the least popular scoring 72 and the most popular 316. (Note that the videos produced in the project are not uploaded to YouTube. To retain control of copyright and to guarantee that they are freely available, they are only posted on the project's website). For technical reasons, so far the number of downloads unfortunately could not be monitored.

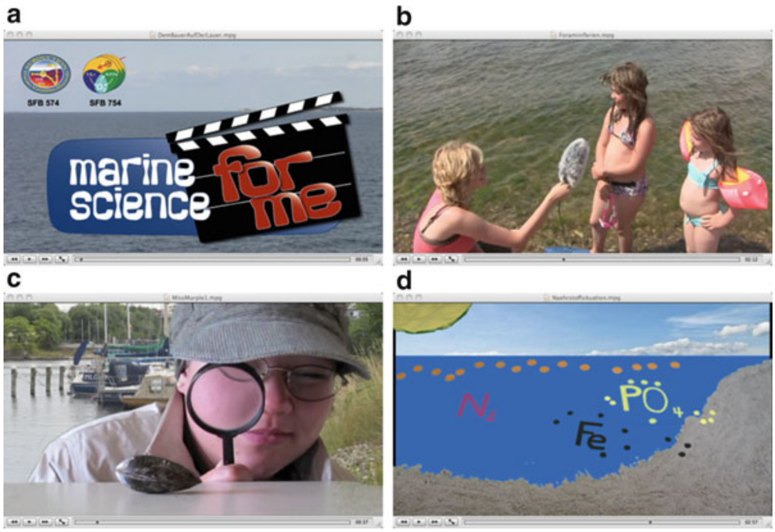


Fig. 5 Still shots from several completed videos: (**a**) Opening sequence of SFB Outreach videos; (**b**) Interview at the beach (from "Foraminiferien"); (**c**) Private eye "Miss Murple" investigating the death of a mussel; (**d**) Cartoon from "Nutrient Situation in Oxygen Minimum Zones"

Frameworks for stories range from children's TV formats (frequently involving "interview the scientist"-style segments) to love stories and parodies of thrillers. Videos are produced with live acting, puppets or – in one case – digitally animated characters. Topics cover background information on tsunami generation or plate tectonics but also specialised research methods like the use of benthic foraminifera in sediment cores as climate proxies. The choice of topic depends on the complexity of the subject itself, the availability of researchers (who all have their own special research interests) to support the pupils and – when working in the classroom context – the teacher's options for accommodating topics within the curriculum.

The outreach project is defined as an intrinsic component of the scientific consortia, and, as a consequence, scientific support is provided by all levels of staff, from principal investigators to graduate students and technicians. Many of the scientists enjoy their involvement in the video productions as long as this does not impose too large demands on their time. The total time contributed by individual researchers depends on their level of involvement in a specific video project. This may range from 4 to 20 h for a single project. Participation is on a voluntary basis and without financial compensation. Involving graduate students and postdocs frequently turned out to be even more valuable than working with senior staff, because of less severe time restrictions, the smaller age gap relative to the pupils and the chance for the pupils to address their career questions to people who had just left university. Graduate students and postdocs optionally receive certificates attesting their involvement in outreach work for reference in their CVs.

Considerable voluntary work is also contributed to the project by the schools, where teachers and pupils are involved in different combinations and for different

Table 1 Statistics of SFB Outreach's video projects between January 2010 and August 2011 (in reverse chronological order)

Video projects	Topics	Schools	Pupils	Videos	Duration
Summer school 2011	Plate tectonics; oxygen minimum zones	Various	12	3	14 days
Science in clips (4 periods)	Benthic communities; cold seeps; tracers and mixing	Freie Waldorfschule Kiel	4*15	4* (2 to 3)	4*2 months
School science project	Nutrient cycles	Ravensberg, Kiel	20	4	4 weeks
After-school activity	Temperature reconstruction from oxygen isotopes	Gymnasium Wellingdorf, Kiel	3	3	1 school year
Summer school 2010	Climate reconstruction from foraminifera in sediments	Various	15	4	6 days
Project week	Role of bacteria	Gymnasium Bad Segeberg	20	2	1 week
Ocean currents	Current measurements	Gymnasium Heikendorf	2	1	1 week
Measurement methods	Oxygen titration; spectrophotometry	Ravensberg, Kiel	20	4	1 week
Internship	Subduction	Various	3	1	1 week
Internship	Oxygen minimum zone	Various	3	1	1 week
Winter school 2010	Food chains	Various	2	2	3 days

time intervals (cf. Table 1). Five secondary schools in Kiel and surroundings have been active in specific video projects in the first 2 years, and pupils from a range of other schools were involved in summer courses and internships. After the first projects, some schools have started purchasing their own video equipment to continue this type of work.

SFB Outreach's website ("Marine Science for Me", cf. Fig. 6) constitutes a central hub for the project's visibility. The site features the finalised video clips, an archive of the press releases by both science consortia and supplementary materials for teachers and pupils such as experiment descriptions or worksheets.

A range of problems had to be overcome, mostly related to insufficient experience in video production and often enhanced by this new combination of science video and schools. There were (and occasionally still are) technical problems with editing and post-production. One of the main reasons is that the pupils often forget to store the raw footage and only deliver a fully rendered video to the project team in which errors can no longer be easily corrected. Sometimes, sound quality is miserable and the pupils are no longer available for re-recording. Also, in spite of consultation and feedback by the researchers, scientific facts are sometimes presented incorrectly. Occasionally, copyrights are infringed, or the product is simply of irrecoverable low quality in terms of pictures, sound or content. In these cases, the videos are not published.

Fig. 6 Homepage of SFB Outreach's website (in German, English version in prep)

At the moment, the scientific quality of the videos is still somewhat lower than desired due to an insufficient immersion of the pupils into the science topics. As already pointed out, for most schools, the time frame available to run a project like this is a "project week" of 5 work days. However, all attempts to fit the workload into this framework resulted in projects in which the introduction to the science, by necessity, had to be extremely brief. Since the pupils are asked to only report on science that they themselves have actually understood, the result was that often only a bare minimum of scientific explanation was incorporated into the videos. Meanwhile, other production formats are being tested that dedicate more time to the scientific aspects.

Steering the project into predefined directions in terms of a focus on certain science topics (as desired by the funding agency) proved to be extremely difficult due to the restrictions imposed by teachers' agendas (controlled by the curriculum) and the availability of specific researchers at a given time to support the project. Thus, an even coverage of all topics addressed by a research consortium cannot be guaranteed, and the growth of the "science mosaic" is frequently controlled by supply and demand rather than by a preconceived plan. For example, quite unexpectedly the topics of SFB 754 turned out to be more attractive to schools than those of SFB 574: In spite of the apparent complexity of biogeochemical interactions in oxygen minimum zones, teachers preferred these topics, probably because of the close connection to biology and chemistry in the school curriculum.

Subduction zones and volcanism, on the other hand, which were offered as the first “point of entry” into video projects for SFB 574, were hardly chosen at all. This again becomes plausible in the light of the German curriculum, in which only a small number of hours in class are allotted to physical geography before human geography starts to focus on politics, economics and society.

5 Evaluation

To be able to quantify our conclusions, after the first full school year of producing video clips, feedback was collected on how this method is received among the pupils. Questionnaires were distributed to some of the pupils participating in the production of videos, and the answers are used to re-evaluate goals and practices.

So far, the responses of 30 participants of the “Science in Clips” project (see Table 1) and 26 participants of the two summer courses were analysed. Pupils were given 2-dozen 5-point Likert items (Allen and Seaman 2007), answerable by ticking one of “strongly disagree”, “disagree”, “neither agree nor disagree”, “agree” and “strongly agree”, and they responded to several open, essay-style questions. (To simplify the presentation of results, in the following, both categories of positive and negative responses on the 5-point Likert scale are summarised into one number each and discussed in percentages of the total number of responses given). The analysis of this evaluation does not try to make any pretence at being scientifically sound, nor does the small number of samples allow any claim to statistical reliability. However, the answers confirm many personal impressions of the staff involved and provide sufficient information to allow some first deductions.

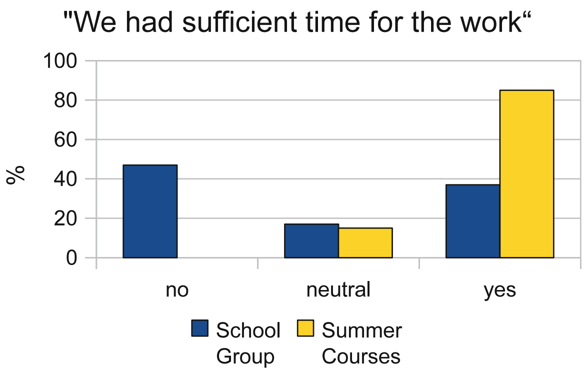
Here, we will differentiate between:

(a) A school group (“Science in Clips”), where participation was compulsory because the video project was part of regular lessons. Time available was 2 times 90 min a week (with the option of assigning additional work as homework) for a duration of 2 months (24 work hours in total plus homework). Four groups of 15 pupils worked successively on four different science topics. Activities by the pupils were graded by the teacher.
(b) The summer courses, in which participation was voluntary. Pupils had to apply for the courses and thus make a conscious choice to spend part of their vacations on this project. Time available was a block of 6 full working days (48 h) in the first and 10 half-days (50 h) in the second course. No grades were given.

5.1 Background of Pupils

Some questions examined how background and expectations may have influenced opinions. Not surprisingly, the summer school pupils who consciously chose to participate in this project seem to be more pre-inclined to its science content and

Fig. 7 Results of survey of participants, in per cent of total replies ($n=56$)



also to video production: 65 % had previously worked with video (40 % in the school group), 77 % considered their grades in sciences as "generally good" (60 % in school) and 64 % had already been interested in sciences before the project (vs. 43 %). Pupils in the summer courses were slightly younger (grades 9–11) than those of the school class (grade 12), but it is not clear if this should have implications for the replies.

5.2 Satisfaction with Proceedings

Happiness or unhappiness with proceedings may decide how well a project is received and thus have repercussions on the responses. Most of the pupils generally appreciated the project: In the school group, 83 % liked "learning science in this way" and 90 % enjoyed the combination of scientific content and entertaining "packaging". (These questions were only asked in the second of the summer courses and received 100 % affirmation). The overwhelming majority in both groups was quite happy with the assistance they received (73 and 92 %) and confirmed that "The introduction to the science was good" (77 and 88 %).

However, 10 % of the school group disagreed with this statement (0 % in the summer courses), and a considerable fraction at school found their science topic difficult (30 vs. 8 %).[1] In the classroom situation, time management issues also turned out to be a severe problem: Only 37 % of the pupils at school felt they had sufficient time for the task (85 % in the summer block course, Fig. 7). Twenty-three per cent thought that the requirements were too high for the available time (0 % in the summer courses) and 13 % stated that they sacrificed too much of their free time

[1]It should be kept in mind that the pupils' answers do not refer to the same introduction to science because scientists and topics were not identical for the different courses.

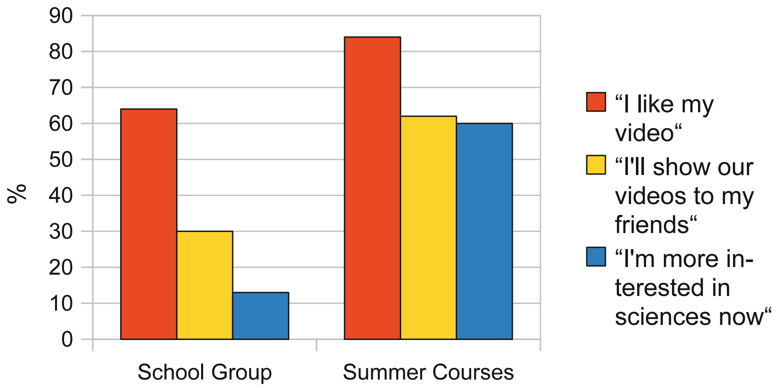


Fig. 8 Personal perception, “courage for dissemination” and change in interest ($n = 56$)

for the project. In retrospect, 20 % of the school group would have preferred “normal classes” to doing a video clip. (This situation is elucidated somewhat by the open questions, in which several pupils pointed out that they would have liked to receive a lot more in-depth information on the science. Also, the misconception that this class was supposed to be on biology led to some unrest among pupils who had to work on topics in ocean physics).

5.3 Impact

How did the pupils evaluate the results of their courses? The majority liked the video they themselves had produced (64 and 84 %). Yet, from a less subjective perspective (“I will show our videos to my friends”), only 30 % of the school group still answered affirmatively (62 % in the summer courses, Fig. 8). The – admittedly ambiguous – statement “I am now more interested in sciences” received only 13 % affirmation in the school group but 60 % in the summer courses. (“Ambiguous”, because a highly motivated science pupil would be forced to say “no” if his/her level of motivation remained high).

In both groups, there appear to be positive correlations between prior interest and an increased interest for sciences afterwards and also between above-average grades in science subjects and an increased interest in sciences after the course. In the school group, no pupils at all went from “previously not interested” to “now interested”, but in the summer school, 3 cases (11 %) claimed they did; 3 pupils from the school group (10 %) and 1 from the summer school (4 %) went from undecided to positive.

Only 23 % of the school group were willing to join similar projects if offered as a voluntary after-school activity (58 % in the summer courses).

5.4 Results from Essays

In the replies to the open questions, a recurring topic was the difficulty in writing a storyboard. Clearly, this is something where pupils need considerable support. However, several also felt insufficiently prepared for it because they did not have enough time to get immersed thoroughly into the science topic. This issue did not come up in the second, longer summer course, where as a result of previous experiences, more time was allotted to hands-on experiments. In the school group, the pupils also complained about the lack of cooperation of some of their less motivated teammates (a fact that also became apparent to the staff during lessons). A few pupils in the school group complained that participation in this project was not on a voluntary basis.

Positive feedback came with respect to the attractiveness of the task (i.e. explaining science in a fun way), the large amount of creative freedom the pupils had and the positive team experience that was present in many (although not all) teams.

5.5 Additional Observations

Contrary to expectations, the pupils frequently turned out to be “conservative” with respect to experimenting with new formats in storytelling. Instead of striving for originality and coming up with new ideas, quite often they tried to reproduce well-known TV formats (e.g. interviews with scientists, documentaries or children’s science programmes). Although not completely in the spirit of the project, in the initial phases, this “quick and easy approach” was acceptable to get started because technical issues required a considerable portion of the available time. Meanwhile, however, more time is dedicated to the creation of “more adventurous” styles and storyboards. Positive examples include a “silent movie”, a video clip set completely in black light, a love story between two species of zooplankton, and a “Mission Impossible”-type story about tagging water masses in the ocean with tracer substances.

Closer scrutiny of the videos so far produced shows that pupils still tend to perpetuate some of the common stereotypes of scientists. Even researchers whom the pupils only met in street clothes are deliberately portrayed in white lab coats “to make it easier for kids to identify the scientist” (Fig. 9). On the other hand, instead of the typical “male scientist”, we now frequently encounter girls impersonating a female scientist, indicating that their perception of science is no longer entirely dominated by male representatives.

Further evaluations will be carried out with participants after the second school year. In addition, as more clips are becoming available on the website, the need now arises to survey and document how they are being received and used by the target groups. To what extent do teachers introduce them into their classroom? Are pupils showing them to their friends? For this, additional feedback mechanisms will be set up to allow communication with the audience.

Fig. 9 Pupil impersonating the stereotype of a scientist for a video clip

6 Conclusions and Lessons for Future Work

The first phase of this project demonstrated that the joint production of scientific video clips with pupils and researchers is feasible and can be profitable for the participating schools as well as the research institute. The teaching at school is enriched by the new focus imposed by this product-centred, hands-on learning, and the scientists discover new ways of communicating geosciences. Nevertheless, this approach has a steep learning curve; it is time intensive and requires considerable resources in terms of equipment and manpower. (The largest single cost factor being a position for a person coordinating all these activities and providing the necessary know-how).

Involving pupils on a voluntary basis (e.g. in after-school activities or summer schools) attracts participants with higher motivation and yields better results than "forced labour" imposed within the framework of regular school work. The hope that these projects might win over pupils who had no previous interest for sciences does not seem to come true in the majority of cases. However, pupils who were already inclined to sciences tend to get confirmed in their interest, which will ideally encourage a decision to choose a career in geosciences. For a research institute thinking about engaging in this kind of activity, the obvious conclusion would be to only work with selected pupils who have to apply to participate. This is legitimate if the research institute can manage a video project on its own. However, in cooperation with schools, this approach is not always possible because teachers have the task of reaching all their pupils and not just a select few.

Although the first video products cannot aspire to qualify as highlights of scientific journalism, they do show the potential of the medium. Quality varies between different productions, but as experience accumulates, the focus of the work gradually shifts from tackling technical issues of video production to directing the creativity of the participants towards more originality and improved scientific content of the video clips.

The ultimate appeal to target groups remains to be seen, but feedback from the pupils, teachers and scientists involved in the productions as well as from visitors at first public screenings of the videos is largely positive. Successful videos are recommended to friends, family and colleagues, and they are beginning to be appreciated by teachers as an alternative to standard textbook material for introducing new science topics in school. Quite unexpectedly, test screenings to research staff showed that even graduate students enjoy the videos because they offer a simple first step into some of the more complex interdisciplinary topics of the research consortia.

The first video clips published on the project's website immediately generated a demand for further information to accompany them. While the videos incite curiosity, supplementary written material is required to explain the topics more in depth. Thus, new video projects will make an attempt to include a "documentation" component from the very beginning.

To the initial disappointment of the research consortia, it turned out to be impractical to convince the schools to focus their videos only on those research results that were new and ground-breaking. Meanwhile, however, the highlights of the consortia's research are beginning to show up in the emerging video-mosaic nevertheless. When the researchers present their latest results to the pupils with obvious excitement, the pupils recognise that this must be "cool stuff" and adopt it for their videos with great enthusiasm. In this way, the transfer time of several years that is usually required for new research to make it from the scientists to the schools is reduced to a few months.

Overview

Background and Motivation

– SFB Outreach communicates the research background of two research consortia in ocean sciences to schools and via its website to the broader public.
– Together with scientists, pupils from secondary schools produce "edutainment" video clips on research topics.
– Videos are presented on a dedicated website in "YouTube style": short, original and addictive.

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Innovations and Findings

– In 2 years, various projects with groups of pupils or whole school classes have been carried out, varying in length from a few days to a whole school year.
– At present, about two dozen video clips are available on sfb-outreach.geomar.de and new productions are underway.
– The topics covered range from "tsunami generation" to the "use of benthic foraminifera in sediment cores as climate proxies". Presentation styles include love stories, newscasts or children's TV formats.

Implications for Wider Practice

– The feasibility of the approach has been successfully demonstrated, but it includes a steep learning curve for all partners involved.
– From feedback to the first projects, lessons on improved strategies can be derived, e.g. with respect to minimum time frame for individual projects and recruitment of pupils.
– The project primarily attracts pupils already interested in geosciences; it confirms them in their interest and motivates them to further pursue sciences.

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Small, Subject-Oriented Educational Resource Gateways: What Are Their Roles in Geoscience Education?

Matteo Cattadori, Cristiana Bianchi, Maddalena Macario, and Luca Masiello

1 Introduction

Nowadays, teachers turn more and more to the web for everyday support in their profession.

They mainly use this tool to look for resources when preparing a lesson. For example, in Italy the portion of teachers that state they "regularly use the Internet to browse websites for data and information to use in their daily work" has risen from 7 to 40 % over a 10-year period (Cavalli 2000; Cavalli and Argentin 2010).

This trend has encouraged many Ministries of Education to set up services, which have already been active for some time, specifically aimed at providing teachers with professional assistance. Online resource archives of educational materials, so-called information gateways, are among the most appropriate tools to meet these needs. Almost all European Ministries of Education have one, mainly targeted at their own teacher population. These gateways have in common a top-down distinctive trait.

Another feature they share can be found in the topics of the educational resources available in their databases. All ministerial gateways gather together resources on all school disciplines, suitably organised. These tools can thus be called generalist.

M. Cattadori (✉)
Education Section, Museo delle Scienze (Trento Science Museum), Trento, Italy
e-mail: mcattadori@gmail.com

C. Bianchi
Section of Mathematics, Science and Technology, IPRASE Centre for the Career-Long Professional Learning and Updating of Teachers of Trento, Trento, Italy

M. Macario
School of Science and Technology, University of Camerino, Camerino, Italy

L. Masiello
Department of Sociology and Social Research, University of Trento, via Feliciano 8, Verona, Italy

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In fact, their resources are sorted by topics (title of the metadata: "Subject") that adopt a USC (Universal Scheme of Classification) covering all subject areas.

Within geosciences education, one of the most important key concepts is the fact that "Earth is a complex system of interacting rock, water, air and life", which appears in many reference documents like the Earth Science Literacy Principles (http://www.earthscienceliteracy.org/) and the syllabus of the Earth Science Olympiad of International Geoscience Education Organisation (IGEO, http://www.geoscied.org/). If it is so important for education to focus on the interactions between the different spheres of the Earth system, then doubts may be raised against traditional generalist classification methods, as these could hinder the search for multi- and interdisciplinary resources.

More data supports the thought that a universal scheme of classification covering all subject areas is not "quite appropriate" to organise Earth science educational resources:

1. The Development of a European Service for Information on Research and Education Information Gateways Project Handbook (DESIRE Consortium 2000) states that in Earth science, different schemes of classification exist: the handbook advises that in these cases the adoption of Universal System of Classification could lead to problems in the realisation of services.
2. "Subject" is one of the three main metadata (together with age range and keyword) employed by users when searching existing educational resource gateways (pers. com. Dr. Panzavolta of the Istituto Nazionale di Documentazione, Innovazione e Ricerca Educativa (INDIRE, http://www.indire.it/). This means that the more accurate the definition of the field "Subject", the greater the chance that users will succeed in finding resources that match their request.

This chapter illustrates the processes and results achieved by the Inquiring on Climate and ENergy project (I-CLEEN, http://www.icleen.museum/), whose main goal was to set up an educational resource gateway about Earth science, with features that are quite opposite to the ones displayed by the top-down/generalist gateways described above. This ambition stemmed from the conviction that the fundamental traits considered above cannot suitably emphasise the importance of interactions and of system complexity, an aspect that is vital in geoscience education.

Due to this fact, the I-CLEEN project gateway presents both bottom-up and discipline-oriented features. Bottom-up because it has been created through a professional cooperation process between teachers and the project editorial team educators, supported by the leading institution of the project, the Trento Science Museum. But also subject oriented since for the metadata "Subject", it adopts a vocabulary of values customised on the topics that belong to the Italian curricula of the Earth science school discipline. For instance, an educational resource on CO_2 on "traditional gateways" has these values of the metadata "Subject": biology, ecology, chemistry and environment. On the I-CLEEN archive, these values are as follows: Interactions of the Atmosphere, Interactions of the Biosphere, Climate and Greenhouse effect.

Examining this case and its results can point out critical elements and ideas that may help to gain a deeper understanding of the role these tools play in providing teachers with professional assistance.

2 Motivation and Rationale of the Project

The reasons behind the I-CLEEN project are the product of long deliberation and analysis of the profile of the Italian teacher of science in general and of geoscience topics in particular.

The process was fuelled by an initial set of driving forces. Among the most important was the analysis of the data collected by the Trento Science Museum during the assessment of the educational activities that its Educational Services department offers schools both from the Trentino Province and from all over the country.

The Trento Science Museum is a public institution that promotes science culture on local and national scale, with scientific research, temporary exhibitions, events for the public and educational activities. The latter engage over 50,000 schoolchildren each year, while more than 250 teachers take part in refresher courses and workshops. Each of the professional development activities for teachers ends with a quality assessment aimed at evaluating the effectiveness of the training. The analysis of the results seemed to indicate that geoscience teachers did not have enough support in the development of their active lessons, and the available resources and tools did not meet their needs.

These findings gave start to a preliminary evaluation, made by the Educational Service team. The main focus was on the profile of today's Italian geoscience teacher and the process was enhanced and guided by the considerations that stemmed from the professional experience of the group's members.

In Italy the school system is organised with the primary school students whose ages are from 6 to 10 and the secondary school students whose ages are from 11 to 18. Compulsory school ends at age 16. In the secondary school (split in first from 11 to 13 and second level from 14 to 18), geoscience topics are mainly included in the following two school disciplines according to the dispositions of the Italian Ministry of Education:

- In the first level: mathematical, chemical, physical and natural science
- In the second level: natural science, chemistry and geography and microbiology

These are taught by an estimated population of 48,000 teachers (Greco 2010).

The following three sets of findings were identified during this preliminary process:

1. The profile and role of teachers in general and of science teachers in particular in Italian first- and second-level secondary schools
2. The links between geoscience research and the world of communication
3. The role of ICT in school as a tool that supports teachers' work

Each of these is described in detail in the following three paragraphs.

Proof that these observations were meaningful emerged quite some time after they were formulated, during the interviews with the teacher-users of the I-CLEEN service, which were performed to assess its effectiveness.

2.1 The Profile and Role of the Italian Science Teacher

The Italian teacher is a rather complex figure and available surveys highlight a very structured range of aspects. This clearly emerges from many surveys, performed both on a national and international level.

For example, Italian teachers, as compared to colleagues from 23 different nations (OECD 2009), rank among those most pleased with their job. However, the same studies also show that Italian teachers express a great need for continuing professional development, much more than their colleagues from other nations, especially in ICT and in fields that are strictly linked to the discipline they teach. One Italian teacher out of two strongly demands refresher training and ongoing professional assistance on the topics and on specific issues related to the discipline they teach. This emerges from both editions of one of the broadest and most intensive surveys on the teaching profession, which were carried out in Italy by the Political and Socioeconomic Research Institute (IARD-RPS, http://istitutoiard.it/) within 10 years of each other (Cavalli 2000; Cavalli and Argentin 2010).

If we narrow our field down to science teachers, data is available only on a European level. One of the most influential documents is the Rocard report (European Commission 2007), carried out by a panel of six experts appointed by the European Commission to enquire into the origins of the declining interest among young people for science studies. These were found largely in the way science is taught in schools. The same report indicates, among its findings and recommendations, the following two elements:

- "The teacher's role as key player in the renewal of science education".
- "A reversal of school science-teaching pedagogy from mainly deductive to inquiry-based methods provides the means to increase interest in science".

Such a change in teaching methods requires adopting less passive-deductive educational practices. Among these, the report specifically names Inquiry-Based Science Education (IBSE) practices that belong to the wider class of approaches to teaching commonly said to be "student centred". A partial list of these is the following (Michael and Modell 2003):

- Problem-based or case-based learning
- Cooperative/collaborative learning/group work of all kinds
- Think-pair-share or peer instruction
- Conceptual change strategies
- Inquiry-based learning
- Discovery learning
- Technology-enhanced learning

A characteristic that is common to each of these educational practices and that sets them apart from deductive-passive approaches is the fact that they all require teachers to dedicate considerable and objective efforts to the preparation of the materials needed to present them in the classroom.

The current state in Italy of educational and/or geoscience practices mainly used by teachers is well illustrated by the following points:

- Seventy per cent of Italian teachers in schools of all grades state that they often use "transmissive, one-way approaches such as traditional lectures and discussions to provide information" (Cavalli and Argentin 2010).
- There is an increase in the percentage of teachers that turn to traditional direct teaching models (Cavalli and Argentin 2010).
- The average age of the teacher population is among the highest in the world. In secondary schools (both first and second level), 56 teachers out of 100 are over 50 years old compared to an OCSE average of 34 % (OECD 2010). As a consequence, Italian teachers' educational experience is likely to be much longer.
- Professional cooperation among teachers, trading ideas and supporting each other in educational activity planning, is very low (Cavalli 2000; Cavalli and Argentin 2010).
- In Italy geoscience topics are part of a wider teaching discipline and can be taught by graduates in chemistry, geology and biology. However, many more biology graduates become teachers than geology graduates do. The only element available on this issue (Costa and Emiliani 1982) states that there is a 5:1 ratio between these two qualifications. Consequently, many teachers (those with a biology background) must make an additional effort to carry out a student-centred geoscience lesson.
- During compulsory education (6–16 years of age), and according to the data of the Ministry of Education (Ministero della Pubblica Istruzione 2006), the fraction of students that aren't admitted to the next class is mainly concentrated in the last year of first level and in the first year of second level of secondary schools (Table 1). The science curricula of these 2 years mainly deal with geoscience topics (Ministero della Pubblica Istruzione 2007).
- Previous research on geoscience education has already shown that, according to teachers, the possibility of carrying out experimental activities is limited by the fact that handbooks and activities to support them with are difficult to find (Greco 2010).
- The 2009 second-level secondary school reform has brought about a reorganisation of geoscience education in lyceums (one of the different types of second-level secondary schools in Italy), with the discipline being now taught to 14–15-year-old students rather than to 18-year-olds (Ministero della Pubblica Istruzione 2010). This means that science teachers cannot rely on students' former science knowledge. It is very likely that in response to this change teachers will need to develop new experimental approaches to geoscience education.
- Another consequence of the reform is the fact that the number of class periods for science disciplines has decreased in second-level secondary schools. This could make it even more difficult to dedicate time to geoscience and/or to experimental approaches.
- Finally we mustn't forget that there are countless reasons that stress the importance of ensuring correct geoscience education. In fact, 70 % of the Italian territory is

Table 1 Students that were admitted to the following school class with "formative debt"[a], reported by second-level secondary school type and school year (per 100 examined) – both national and private schools – school year 2004–2005

	School year				
	Total	I	II	III	IV
TOTAL	36.3	34.8	37.9	35.7	37.1
Lyceums[b]	30	29.2	31.2	30.8	28.7
Socio-pedagogical lyceums	34.3	34.2	36.1	34.3	32.1
Technical schools	39.4	36.5	40.2	40.1	41.3
Professional education	41.8	39.2	43.9	–	43.1
Artistic education	39.8	39.1	41.6	37.2	41.1

Source: MPI – review of the end of the year results

[a]Meaning that students can go on to the following school year but must make up for poor results in specific disciplines with extra tutoring followed by an examination

[b]Italian lyceums are the equivalent of US and UK high schools

classified as high hydrogeological risk area. Furthermore, the ratio of damage caused by earthquakes to the energy released during these events is much higher than in other countries (Protezione Civile; http://www.protezionecivile.gov.it/).

Taking these elements into consideration, the I-CLEEN project team reached the conclusion that a highly critical issue is not only the development of IBSE geoscience lessons as recommended by the Rocard report. Moreover, the same is also true for the development of any activity adopting a student-centred approach (Lea et al. 2003).

For many Italian science teachers, it requires a great deal of extra work in lesson planning, and it is likely, on the basis of the elements illustrated above, that this forces them to take up passive teaching methods more often or, even worse, to avoid geoscience topics altogether.

2.2 Links Between Geoscience Research and the World of Communication

Scientific research studies on Earth's climate system mainly belong to the area of geoscience. During the first decade of the twenty-first century, this field of research received a great deal of attention both by the public opinion and by the media, mainly due to sensational events such as the Nobel Prize awarded to Al Gore and IPCC and international climate change conferences such as COP15. Science communication in the media is often so misleading and/or inaccurate that researchers have become more aware of the important role played by correct communication. As Doran effectively states (Doran and Zimmerman 2009):

> The challenge, appears to be how to effectively communicate this fact to policy makers and to a public that continues to mistakenly perceive debate among scientists.

The main goal of improving science communication encouraged many researchers (also outside the field of geoscience) to take up new means to make their work public, also adopting interactive science publication models, such as the Public Library of Science (PloS, http://www.plosone.org) and Research Blogging (http://researchblogging.org/). This was also enabled by new, suitable technological tools that were available at relatively low costs.

As far as the specific field of geoscience is concerned, a few scientific research projects developed communication programmes that specifically targeted schools. An example is the Antarctic Geological Drilling (ANDRILL, www.andrill.org), a scientific research programme integrated with palaeoclimatic goals that involved researchers and teachers from four countries: the USA, New Zealand, Germany and Italy. ANDRILL developed an extensive and innovative education and outreach (E&O) plan, called ANDRILL Research Immersion for Science Educators (ARISE, http://www.andrill.org/iceberg/arise/index.html) (Harwood et al. 2006; Huffman et al. 2009), as an integrated part of its scientific programme throughout the whole project from 2006 to 2008. ARISE was developed to meet the requirements made by the National Science Foundation (NSF, http://www.nsf.gov/), who funded the project, as stated in the "Broader Impact Criterion" document (NSF 2007). The main goal of ARISE was to provide information on the aims, methods and results of the research activity to the public and the world of school and education, thus including them in the project (Huffman et al. 2009).

Communication programmes of this kind yielded positive results in schools, also in the long term (Cattadori et al. 2011). This fact, together with the observations illustrated above, led the I-CLEEN team to conclude that it would be possible to cooperate fruitfully with geoscience researchers in general, and not only with the researchers of the Science Museum, at specific and innovative projects that would support active learning in geoscience.

2.3 The Role of ICT in School as a Tool That Supports Teachers' Work

A wide majority of surveys on teaching clearly show an increasing trend in the use of Internet as an information source in lesson planning. In Italy the percentage of teachers that state they do so daily rose from 7 to 40 % of the total population of first- and second-level secondary school teachers (Cavalli 2000; Cavalli and Argentin 2010). One of the most appropriate ICT tools in lesson planning is the information gateways of educational resources.

During the I-CLEEN preliminary study phase, the development and management projects for many educational material information gateways available on the Internet were analysed. Among these, attention was mainly focused on the following: Gateway of Educational Materials (GEM, http://www.thegateway.org/), Multimedia Educational Resource for Learning and Online Teaching (MERLOT, http://www.merlot.org/merlot/index.htm), Learning Resource Exchange (LRE http://lreforschools.eun.org/) and the Digital Library for Earth System Education (DLESE, http://www.dlese.org/).

Data was collected for analysis by simulating a real-life situation, in which a teacher, wanting to develop an active geoscience lesson for her class, would make use of these tools to gather the necessary resources.

The main feature of these gateways is the extreme diversity of topics they cover (all of them, apart from DLESE) provide educational material in all school disciplines, including non-scientific ones and a wide variety of resource types provided and reported (from individual pictures to ready-to-use experimental activities, from slide presentations to photo galleries of field outings).

This characteristic is also due to the fact that more than one of these gateways have acted as collectors for other educational resource archives assuming huge dimensions, even of some hundred thousand resources, often in many different languages. These archives truly represent an authentic cultural legacy of educational practices and provide incomparable insight on teaching and learning in present-day schools all over the world.

However, from the point of view of their effectiveness in supporting teachers in their everyday work, they are so vast and diverse that users often feel disoriented. The searches made seldom provide resources that help reduce or at least facilitate the process of developing an active lesson, even though they are conducted with the advanced search tools that the gateways offer.

3 Objectives

I-CLEEN set out to provide Italian teachers with support in developing active geoscience lessons. This had to be consistent with the features highlighted in the previous paragraphs.

The aim of the project was first to set up (between September 2008 and January 2010) and subsequently manage (starting from January 2010) a “quality-controlled subject gateway” of resources for active education on geosciences topics, with the contribution of the Museum’s researchers.

Koch’s definition of “quality-controlled subject gateway” (Koch 2000) has been adopted, since it emphasises that one of the most important criteria of these instruments is the use of deeper levels of classification for the subject/browsing structure of the service.

4 Methods

4.1 The Project Team

In 2008, the Museum selected a group of five experienced geoscience teachers proficient in ICT educational tools to form the editorial team that would set up the I-CLEEN service.

One of these was relieved from teaching and temporarily transferred to the Museum to coordinate the project. Another is both a teacher and a member of the Laboratory of Physical Science Communication (LabCosFi) of the Physics Department of Trento University. By joining the efforts of different institutions, the project tries to put into practice one of the four "common principles" illustrated in the European Commission's document "Common European Principles for Teaching Competence and Qualification" (European Commission 2010). These aim to provide an impetus for developing policies that will enhance the quality and efficiency of education across the Union. The principle mentioned above states that the profession of teacher should be based on partnerships and that institutions providing teacher education should organise their work collaboratively in partnership with schools, local work environments, work-based training providers and other stakeholders.

4.2 Practices and Models Followed

The editorial team had no experience in projects of this kind, so they chose to adopt the approach illustrated in the DESIRE handbook to get the process of setting up the I-CLEEN project off the ground. The handbook aims to support the development of large-scale gateways in Europe for high-quality research information on the Internet.

Other tools supported and guided the I-CLEEN service design phase, among which are:

- The Strategic Project Management Toolkit for Creating Digital Literacy Initiatives (SPreaD 2008), to define the process in detail and to establish the output of each step of the design process
- LRE for all the gateway technical documents. LRE is the reference service that links and provides technical guidelines for gateways of European Ministries of Education
- DLESE subject gateway, with which I-CLEEN shares goals, methods and topics
- The experience of the Science Education Resource Centre at Carleton College (SERC) in building educational portals and digital libraries (Fox et al. 2005)
- Counselling by INDIRE, to help to develop a consistent resource metadata structure

Right at the start, the type of lesson that teacher-users would devise with the support of the I-CLEEN project services had to be defined: a decision that would influence all subsequent steps. The IBSE approach would have been the ideal choice, on the basis of the Rocard report guidelines already mentioned above: in fact, IBSE is considered a key element of science-teaching innovation in school. However, the macro-category of active learning which, as defined by Bonwell (Bonwell and Eison 1991), involves students in doing things and thinking about the things they are doing, and which contains IBSE (see list in the "Motivation" chapter), was preferred as a reference model in the design of the I-CLEEN service since it's targeted mainly on Italian science teachers.

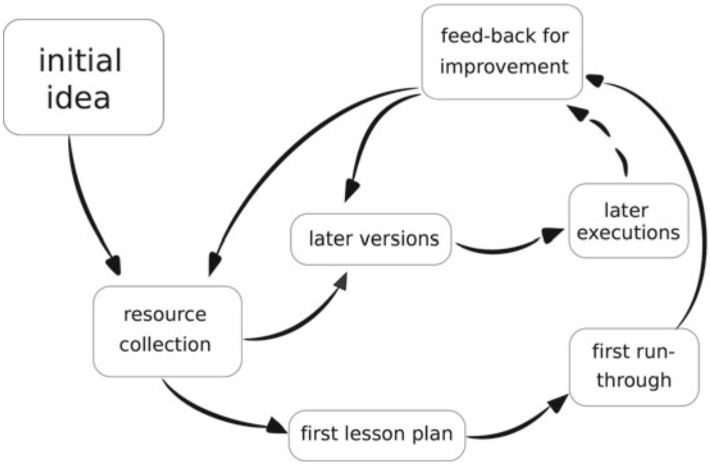

Fig. 1 The diagram of the life cycle of a student-centred lesson adopted by the I-CLEEN project and adapted from the original diagram of Kemmis and McTaggart (1981)

In fact, one of the main aims of the project was to promote the educational experiences that science teachers had already developed and also to show how valuable cooperating and exchanging information/experience is for teachers. These goals wouldn't have been met if IBSE had been chosen, as this would have drastically narrowed down the resource archive (recall previous chapter saying that 70 % of teachers "often" use passive teaching methods).

Subsequently, the steps that teachers must make to develop an active lesson were examined in detail, also attempting to shed light on the link between lesson/activity and resource. A model for active lesson development, illustrated in Fig. 1, was thus defined, starting from a few reference models for the research-action method and especially Kemmis's "action research planner" represented in his "Action Research Spiral" (Kemmis and Mc Taggart 1981).

Figure 1 represents a general diagram of the life cycle of an active lesson, made up of the steps that a teacher should take – from the initial concept to carrying out a well-tested activity. When evaluating resources for the archive, one of the features that are considered most important is their potential to shorten this process.

4.3 Evaluation Process of the Educational Resources

The resource evaluation process for the I-CLEEN website is based on a number of criteria that can be grouped into three sets:

1. Scientific rigour evaluation
2. Educational effectiveness evaluation
3. Educational experience portability evaluation

A detailed description of these criteria was outlined in the selection policy document. This document was created and published according to the DESIRE project handbook guidelines.

Similar projects have adopted control and evaluation mechanisms based on "double peer reviews" like the project Climate Literacy and Energy Awareness Network (CLEAN, http://www.cleanet.org/) which verify both scientific rigour and educational effectiveness. This couldn't be applied to the I-CLEEN project and a different control mechanism was opted for that was based essentially on the experience and exchange of ideas of the members of the editorial staff of the project.

Scientific rigour is evaluated by the group of researchers of the Museum, supported if necessary by researchers of other institutes when the subject of an educational activity doesn't fall into one the Museum's fields of research. The Italian National Institute of Geophysics and Volcanology (INGV, http://www.ingv.it/) is one of the main external research institutes involved in those cases.

Educational effectiveness is evaluated by the teachers of the editorial group, according to the criteria and guidelines provided by their experience. Each formulates an individual opinion that is then analysed by the group. In some cases, the activity is tested in the classroom and the observations registered and processed are used in the evaluation according to the principles of the action research stating that action research is the study of attempts made by teachers to change and improve the practice of education through their reflection on the effects of these actions (Ebbut 1985).

A feature that sets I-CLEEN apart from similar projects is the educational experience portability evaluation. This is carried out in consideration of the specific features that characterise the population of teacher-users that I-CLEEN addresses, which have been illustrated in the previous section "Motivation". Recently this term must take into account new constraints.

Portability is referred to as a set of intrinsic, often objective features that determine whether an activity can be easily employed by a teacher-user in one or more classes.

An educational activity is considered portable if it satisfies the following criteria:

- Materials and/or software are easy to find.
- The teacher-user can adjust the educational activity to different student targets, either making it more simple or more challenging, with a limited amount of work.
- The activity can be performed over a limited number of class periods. This aspect in particular has become critical since the numbers of class periods has been reduced by the mentioned school reform.

"Portability" evaluation has led the editorial team to dedicate some thought to resource presentation methods, to ensure that resources would be correctly displayed and that users wouldn't be misled by complex, hard to use information and tools.

For this reason, resources may be presented in the I-CLEEN archive in one of three possible ways:

1. Simple resource. This is presented using only metadata keywords, without any additional documents.

2. Supported resource. This is also provided with a single “support sheet” with general, non-structured information that helps teachers perform the activity with their students.
3. Complete resource. Provided with two separate documents called “teacher guideline” and “student worksheet”. These present information in a structured form, divided into specific sections.

In theory, the work demand on teacher-users to set up the active lesson should gradually decrease going from the simple to the complete resource.

The templates used to define the structure of the teacher guideline and student worksheet were taken from the Earth Learning Idea projects (http://www.earthlearningidea.com/) and from the activities published in the book “Polar Science and Global Climate – an International Resource for Education and Outreach” (Kaiser et al. 2010), which were devised by an international team of teachers within the Education and Public Outreach programme of the International Polar Year (IPY, http://www.ipy.org/).

4.4 Licensing

As far as copyright issues are concerned, the I-CLEEN project editorial team established that the Open Educational Resources (OER) model was the most appropriate to satisfy their needs. OER defines the concept of Open Content similarly to Open Source for software, as proposed for the first time by Wiley in 1998 (Wiley 1998).

All material developed by the I-CLEEN editorial group, which is in part created starting from educational activities indicated or submitted by teacher-users, is published under Creative Commons Attribution – Non-commercial 3.0 Italy (CC BY-NC 3.0 http://creativecommons.org/licenses/by-nc/3.0/it/).

4.5 Metadata

The archive and metadata have been structured according to the Dublin Core Metadata Initiative (DCMI, http://dublincore.org/) standards and later specifications stated by the Learning Object Metadata (LOM) model. Complying to these standards, the following 27 different metadata have been defined:

- Title
- Description
- Author
- Coauthor
- Contributor
- Cataloger
- Version

- Rights
- Costs
- Language
- Subject
- Keyword
- Age Range
- System Requirements
- Resource Type
- Interactivity Type
- Interactivity Level

Type of values and controlled vocabularies of values that each metadata may assume were defined. Some of these are based on the vocabularies of information gateways that are close to I-CLEEN in topic and aims. For example, the DLESE project vocabulary was adopted for the "Resource Type" metadata.

Special attention was given to the "Subject" metadata, which was also particularly emphasised by the "subject gateway" definition taken up by this project. An original, supervised vocabulary was developed for this metadata, which doesn't follow the traditional LOM subject breakdown. In fact, the editorial team believed it was best to make an effort to devise a system that met the actual needs of the teacher-users and specifically of their curricula. As a consequence, the I-CLEEN "Subject" metadata vocabulary is original and was developed according to three main documents:

1. The International Geoscience Education Organization documents (the syllabus in particular), developed for the International Earth Science Olympics (IESO)
2. The Principles of the Earth Science Literacy Initiative
3. The National Guidelines for Curricula

Thanks to INDIRE's collaboration, the entries of this customised vocabulary were subsequently mapped to the ones traditionally adopted in similar projects, so that the I-CLEEN gateway could exchange data to and from similar services. The results are shown in Table 2.

Once the metadata were established, the entire system of connections among elements was defined in detail. A key condition identified by the editorial team was that the system had to be extremely flexible, so that each educational resource could be made up of various materials, which could differ both in number and in nature (files, URL, documents of different kinds).

Such complex and structured requirements guided the choice of the IT tool for the I-CLEEN website implementation towards LifeRay 5 (http://www.liferay.com/). This is based on Java language and, although it had never been employed in projects such as I-CLEEN before January 2010, it had been adopted for the management of complex corporate websites. In fact, it is an Open Source Software that easily adjusts to structured demands.

Thanks to this tool, the editorial team was provided with a reserved area on the website, fully equipped to enable easy, frequent and effective interactions as required by the cyclic educational resource production process. The system can also manage a vast number of user profiles, groups and their privileges.

Table 2 Results of the mapping of the metadata "Subject" between the vocabularies of the I-CLEEN gateway and the LRE thesaurus (http://lreforschools.eun.org/web/guest/lre-thesaurus)

Value of the metadata "Subject" in the I-CLEEN archive	Results of the mapping with the values of the metadata "Subject" of the thesaurus LRE
Measure – measurement units	No mapping[a]
Measure – measuring instruments	No mapping[a]
Measure – quantities	Measuring instrument[b]
Earth in the space – stars and solar system	Celestial body[c]
Earth in the space – the planet Earth	Celestial body[c]
Earth in the space – representing the surface of the Earth	No mapping[a]
Atmosphere – the atmosphere	Atmospheric phenomenon[c]
Atmosphere – weather and climate	Climatic phenomenon[b]
Atmosphere – interactions	No mapping[a]
Hydrosphere – properties of water	Water[c]
Hydrosphere – hydrologic cycle and continental water	No mapping[a]
Hydrosphere – oceans	Ocean – sea[b]
Hydrosphere – cryosphere	No mapping[a]
Hydrosphere – interactions	No mapping[a]
Geosphere – minerals and rocks	Mineralogy[c]
Geosphere – lifecycle of rocks	Mineralogy[c]
Geosphere – interactions	No mapping[a]
Geosphere – volcanoes	Volcano[b]
Geosphere – earthquakes	Earthquake[b]
Geosphere – Earth inner and plate tectonics	No mapping[a]
Geosphere – surface dynamics	No mapping[a]
Biosphere – Earth, life and their history	No mapping[a]
Biosphere – biomes	No mapping[a]
Biosphere – interactions	No mapping[a]
Resources of the Earth – energy resources	Natural resources + energy[c]
Resources of the Earth – material resources	No mapping[a]
Resources of the Earth – sustainability and efficiency in the use of resources	Education for sustainable development[c]
Resources of the Earth – resources, economy and society	Economical resources – society[c]

Legend: [a]No mapping
[b]Mapping 100 %
[c]Partial mapping

The archive was populated with resources, and after its launch, it has been regularly enriched at a rate of one new contribution per week.

The I-CLEEN project organised several events and professional development activities to promote the creation of new resources and the dissemination of the idea that "teaching is sharing": for instance, workshops, teacher refresher courses and meetings. With the same aim and to strengthen the link with the school system, a contest was organised open to all teachers that could win a prize for each activity submitted.

5 Evaluation and Results

Many tools were employed to evaluate the I-CLEEN project, providing an impressive amount of data and information that are extremely heterogeneous both in nature and origin. They will be illustrated in this section, grouped into three main classes:

1. The number of web users reached and their behaviour
2. Service effectiveness
3. Usability and user feedback on the I-CLEEN website graphic user interface

Further general observations on the web service can be formulated on the basis of various kinds of other feedback, coming from different sources: these will be grouped together and presented as the "Additional evaluation" class.

The evaluation methods used for each of these classes will be described, together with the results achieved.

5.1 Number of Web Users and Their Behaviour

Web traffic was assessed using Google Analytics and was put into effect on 1 January 2010, the official web service launch date.

The number of file downloads has been computed since February 2011 with a semi-automatic tool, which simply counts the number of times each document has been downloaded. At the moment, this system lacks additional tools that would allow more detailed data collection and presentation, for example, for a specific time interval.

Table 3 summarises some of the most significant web traffic data for the address www.icleen.museum from 1 January 2010 to 30 September 2011. Month-by-month analysis of web traffic data is illustrated in Fig. 2. This shows that web traffic exhibits a cyclic pattern, with two peaks in November and April: in fact, teachers concentrate their activity in these 2 months to make educational activities fit into the school calendar.

Web access is evenly spread among three different types of sources: direct access (31.83 %), access from other websites (37.64 %) and access from search engines (30.53 %).

The situation that is represented certainly doesn't portray I-CLEEN as an extremely popular website in absolute terms: this is not surprising as the service target population counts a limited number of potential users, which correspond to roughly 50,000 secondary school science teachers.

File download data analysis may provide a further key to interpret the picture with. The system employed to collect this information is rather rough and certainly not as advanced as Google Analytics in terms of result visualisation; however, it provides data that is qualitatively more sound, because the action of downloading a file is more evident both technologically and in terms of web traffic.

Table 3 The main www.icleen.museum server access data (Google Analytics source)

Visits	12,497
Pages views	84,135
Pages/visits	7.16
Average time of visit	5:11
Absolute unique visitors	6,634

The data refer to the time period between 1 January 2010 and 30 September 2011

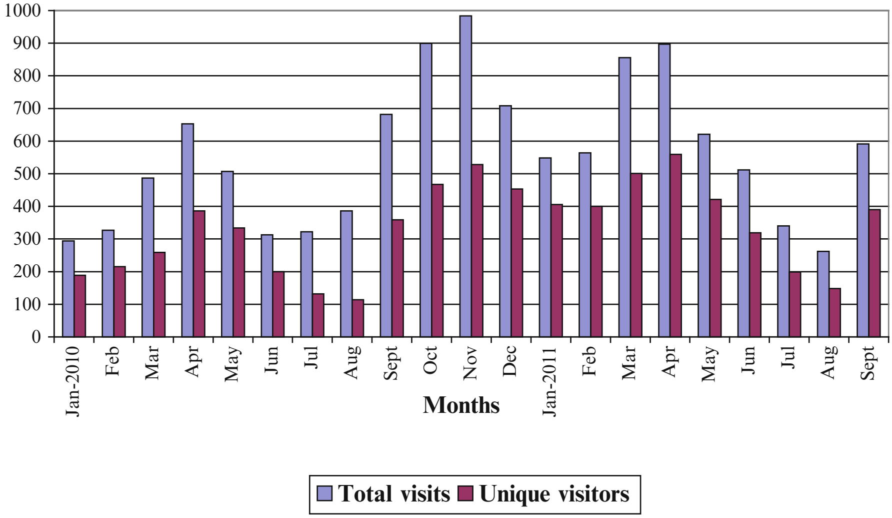

Fig. 2 www.icleen.museum server access data, divided by month. The data refer to the time period between 1 January 2010 and 30 September 2011

Almost 20,000 files of educational material were downloaded from the I-CLEEN archive between February and June 2011. The time span considered is very short, but this surely represents a very good result and could signify that a greater, more widespread use is made of the service than web traffic data seem to indicate.

5.2 Service Effectiveness

This evaluation was performed by one of the co-authors of this chapter, Dr. Masiello, a student of the degree course in Work, Organization and Information Systems of the sociology faculty of Trento University, as part of his graduation thesis work.

The main aim of this study was to assess the effectiveness and efficiency of the I-CLEEN project. To do this, the aims and intentions that guided the editorial team during the project development phase were compared to the actual use made of the service by teachers in order to see what the former evolved into when they were actually integrated in teacher-users' working practices.

A qualitative study was opted for in order to map out the complex relationship between the I-CLEEN platform and its users as precisely as possible, by observing directly how it was employed in different teaching practices.

The analysis was mainly conducted using informal, conversational interviews (Silverman 2002). Twenty-three were performed in total: 8 with development team members (the museum director, 5 editorial team members, the web designer and graphic artist) and 15 with teacher-users.

Whenever possible, this approach was integrated with shadowing observations (Bruni 2005) that made use of the video recordings of users browsing on the I-CLEEN website.

All audio (a total of 40 h) and video (10 h in total) recordings of the interviews were transcribed and then analysed using Computer-Assisted Qualitative Data Analysis Software (CAQDAS) “Nvivo7”, developed by “QSR International”.

The “Grounded Theory” method (Corbin and Strauss 2008) was applied for data analysis. This consists in a process that assigns labels to portions of text taken from the interviews in order to group and organise them according to abstract analytical classes. Thanks to these, the statistician can establish relationships and links between a wide and articulated variety of concepts.

Developer and user data was considered separately. The 2,308 user labels were grouped into the following four classes: Requirements of educational resources, Subject choice, Search channel and Material evaluation.

The 372 developer labels were split into five classes: Project outline, User assumptions, Tool assumptions, Script definition and Diffusion channel choice.

Thanks to user interviews, the main strategies adopted by targeted science teachers to develop a nontraditional lesson plan were outlined.

The development team interviews pointed out the elements that were taken to be critical during the development phase and all the action possibilities (affordances) that were implemented to produce the platform.

The “script” of I-CLEEN emerged from these two sets of elements – where “script” refers to a sort of action plan that is all the different ways the developers imagined the platform could be employed. This collection of data helps to identify those aspects of service use that should be investigated in great detail in order to study the project effectiveness and reliability (Akrich 2006).

The result that emerged most plainly is the need for supplementary educational material (mainly ideas and in-depth information to support educational activity development), stated by Earth science teachers. The data collected show that this demand is greater the more the gap between the topic taught and the teacher’s field of specialisation increases. Furthermore, teachers that are at the beginning of their career require more support than those with a longer teaching experience.

This result was found repeatedly and supports one of the initial assumptions that gave rise to the I-CLEEN project (see chapter “Motivation and Rationale of the Project”).

Source reliability is the subject of the second finding, a key issue in the use of the I-CLEEN service. One of the distinctive traits of the service that has been acknowledged by users is the opportunity to count on a reliable source, represented by the Trento Science Museum. This confirms the lack of influential scientific information channels for Earth science instruction in Italy.

Another result provided by the user interviews relates to knowledge sharing – a topic that proved to be of great importance. Users have stated that it is vital to exchange views and keep up a dialogue with colleagues, but they have also indicated that there is great reluctance to collaborate at their workplace.

I-CLEEN's appeal to adopt open formats was correctly interpreted by users as a call for professional cooperation. Proof of this lies in the fact that there is a perfect match between the terms adopted by users and by developers to describe the characteristics of the service.

The survey also collected elements relating to educational resource "portability", a characteristic that had been introduced by developers. Interviewed users often mentioned that there is a gap between the lessons they'd like to deliver and those they actually carry out. They maintain that this is mainly due to the fact that their school lacks the necessary infrastructures. Due to this, they choose to carry out activities that require materials and tools that are easy to find.

The data for the service effectiveness study was collected mainly using qualitative methods, as this survey was of sociological nature. However, it depicts an extremely rich and detailed scenario of both the I-CLEEN project and the requirements of its users. It also confirms that many of the assumptions made during the service definition and development phases were correct. Some of these, such as the importance of portability, were mere suppositions during the initial phase, which had sprung from the editorials team members' teaching experience.

5.3 Usability Study and Tests

Usability and feedback on use of the I-CLEEN project website was evaluated by Martina Zampieri, as part of her final thesis in the information technology graduate course of Trento University.

All collected data is related to the first release of the I-CLEEN website, which was replaced by the current version on 20 September 2011. This was developed and set up on the basis of the results of Dr. Zampieri's study.

This assessment checked the overall quality of the interaction with the system and pointed out the difficulties users encountered on their tracks. Two different approaches were adopted to evaluate the I-CLEEN website: heuristic evaluation and usability tests.

The former applied the Nielsen method (http://www.useit.com/), in which the detected issues are classified according to 10 well-defined heuristic categories.

The heuristic evaluation of I-CLEEN was performed by a single examiner that explored the website many times using the ten heuristics in a sequence of steps. Site analysis was repeated four distinct times and each time new aspects were detected, which hadn't been spotted during previous interactions. Evaluation took into account one heuristic at a time and, for each of these, a set of key questions checked whether the system behaved according to a specific guideline.

Usability tests were "assignment tests 1"(Polillo 2010) and went through four separate phases: planning, development, implementation and analysis and suggestions. They were performed by placing 12 teacher-users in a controlled environment, supervised by a few evaluators. The users were asked to carry out a set of activities that had been specifically created to find out how certain system functions were employed.

Evaluation and usability tests focused on different aspects. The data they provided were combined accurately to produce the most complete and detailed evaluation possible. The results thus collected were grouped according to three types of issues:

Priority 1: issues with a great impact on usability
Priority 2: issues with a medium impact on usability
Priority 3: issues with a minor impact on usability

Thirty-two issues were detected in total. These became extremely useful, together with the many suggestions that were formulated to solve them, because developers took them as a basis to develop the current release of the service. The version now online hasn't been similarly tested.

5.4 Additional Evaluation

Since the I-CLEEN gateway launch in January 2010, a number of elements emerged that may be included in an overall project evaluation process:

- In May 2010, after the start of the project and without any member of the editorial team knowing about it, European Schoolnet (http://www.eun.org/), the network of Ministries of Education of the 30 European member states, launched a service called SCIENTIX (http://www.scientix.eu/) whose main aims were to:
  - Collect teaching materials and research reports from European science education projects financed by the European Union
  - Find a community for science education in Europe to facilitate regular dissemination and sharing of know-how and best practices in science education across the European Union

By a remarkable coincidence SCIENTIX was created using LifeRay, the software that was also adopted for the I-CLEEN project. At present (September 2011), these are the only two educational resource gateways that make use of this tool. This fact makes direct and complete data exchange between the two repositories possible, and it also indirectly backs up the considerations that led the I-CLEEN team to select LifeRay as the appropriate technological tool for the project:

- I-CLEEN was granted the first prize in the category "Mathematics, Science and Technology" at the European Schoolnet (http://www.eun.org/) eLearning Award 2010. For the award, 539 projects from 39 different countries, some of which were outside Europe, competed.

- I-CLEEN was one of the three finalists for the award put up by the Italian branch of International Council of Museums (ICOM) in the category Information and Communication Technology and open to Italian museums.
- I-CLEEN has been included in the repository (Clearinghouse) of the Open Educational Quality Initiative (OPAL, http://www.oer-quality.org/), a European consortium that also includes UNESCO and that aims to support open educational practices.

Overview

Background and Motivation

– In the education field Earth system science (ESS) is the macro-discipline that has since always been emphasising the multidisciplinary approach to the analysis of natural phenomena, preferring the study of interactions among spheres (geo-, bio-, atmo- and hydrosphere). ESS can offer contents well suited to educate students in continuously switching the study approach from analytical to global.
– Nowadays, among the most widespread tools supporting the work of teachers are gateways of educational resources. Because of their costs, most of these archives are huge, and the system of classification might set back or put down the multidisciplinary approach of ESS.
– Recent changes in the Italian school system on the one hand seem to further threaten geoscience topics.
– Several scientific research programmes developed innovative and effective communication projects based on close cooperation among scientists and teachers.

Innovations and Findings

– The Trento Science Museum fostered a collaborative project among teachers (I-CLEEN), also involving its researchers, aimed at setting up and managing an uncommonly small subject (ESS)-oriented resource gateway targeted on Italian science teachers' needs.
– This gateway adopts Open sources models (for IT instruments and copyright management) and international standards (for processes, metadata and templates).
– During the first 20 months, the service domain recorded low access data. More elements should be taken into account to evaluate the impact of the service more accurately, such as the small-sized population of targeted users and data of document downloads.
– Some of the preliminary assumptions that gave rise to I-CLEEN, like portability of educational resources, have been corroborated during project evaluation.

(continued)

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Implications for Wider Practice

– This Italian experience provides critical elements that could prove useful to improve the generalist gateways that are currently most widespread. These aspects partly emerged as a consequence of assigning a central role to the meta-data "subject".
– The I-CLEEN project results confirm the fact that teachers play a vital role also as advisers for educational resource gateway development: in fact, no one else could outline final user requirements and preferences just as clearly or exactly as they do.

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Part IV
Workshop- and Laboratory-Based Approaches

The European Experience of Educational Seismology

A. Zollo, A. Bobbio, J.L. Berenguer, F. Courboulex, P. Denton, G. Festa, A. Sauron, S. Solarino, F. Haslinger, and D. Giardini

1 Introduction

Earthquakes are the manifestation of a dynamic Earth and easily catch the attention and imagination of people. These phenomena are very well known by any citizen because of the great impact that a big earthquake has on society and the interest of the media in the strongest events. One of the best defences against the effects of earthquakes is citizens who are aware of earthquake risks and consequences, who are well educated in the science of earthquakes, who understand what causes earthquakes, how often, how large and where they are likely to occur and how the damaging effects of earthquakes can be mitigated through appropriate actions, both

A. Zollo (✉) • G. Festa
Dipartimento di Scienze Fisiche, Università degli Studi di Napoli "Federico II", Naples, Italy
e-mail: aldo.zollo@unina.it

A. Bobbio
Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Vesuviano, Sezione di Napoli, Naples, Italy

J.L. Berenguer
Centre International de Valbonne, Valbonne, France

Université de Nice Sophia Antipolis, CNRS, Géoazur, Observatoire de la Côte d'Azur, Valbonne, France

F. Courboulex
Université de Nice Sophia Antipolis, CNRS, Géoazur, Observatoire de la Côte d'Azur, Valbonne, France

P. Denton
British Geological Survey, Keyworth, UK

A. Sauron • F. Haslinger • D. Giardini
Schweizerisher Erdbebendienst (ETH), Zurich, Switzerland

S. Solarino
Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti, Genova, Italy

V.C.H. Tong (ed.), *Geoscience Research and Outreach: Schools and Public Engagement*, Innovations in Science Education and Technology 21, DOI 10.1007/978-94-007-6943-4_10,

European projects: typologies and financial supports

Country	Financial support	School Type	# Schools	Researcher Institutes
Italy	Department of Civil Protecion, INGV; European	Secondary and High schools	15	Universities, INGV
France	European and National	Secondary and High schools	60	CNRS, Geoauzur
Switzerland	European and national	Secondary and High schools	28	ETH
UK	UK Financial Support: Geological Survey Charities OilCompanies Universities	Secondary schools	150	British Geological Survey, UK Universities
Portugal	National	Secondary and High schools	5	University of Lisbon
Greece	National	High schools	5	Patras Seismological laboratory
Ireland	National	Secondary schools	50	DIAS, BGS, IRIS

Fig. 1 A scheme of European projects describing the typologies and financial supports

at individual and community levels. Increasing our knowledge about earthquake phenomena and their impact at the Earth's surface is an important step towards the education and the disaster preparedness of a population in high seismic risk regions.

In this sense, educational seismology represents an efficient vehicle of communication, allowing us to teach and learn about earthquakes and seismic wave impacts through experiments and educational activities (Hall-Wallace and Wallace 1996).

During the last two decades, across Europe, several educational projects in earth science were developed and are ongoing in a variety of situations and national contexts (Fig. 1), with the aim to disseminate meaningful information about earthquake risk and the actions which can be undertaken to reduce or mitigate its effects. Two educational approaches are generally followed (Bobbio and Zollo 2009).

The first one has an immediate impact, and it is strongly based on traditional communication supports such as booklets, brochures, websites, videos, large public seminars and conferences. The end users (students, teachers, large public), following a traditional approach without any experimental practice, generally have a passive role in front of the scientific communication messages. The knowledge about complex natural phenomena has to be acquired through the individual's willingness and understanding capacity.

The alternative approach is instead grounded on advanced technologies by the implementation of seismic wave recording instruments and use of web-oriented and accessible data analysis tools, which provide a direct access to the seismological laboratory practice. In this case, the end user has an active role in the knowledge process by observing, experimenting and measuring the natural phenomena, following modern approaches of interactive science communication which are now pursued by scientific museums such as the Exploratorium in San Francisco, California.

Both approaches are useful and effective in communicating earthquake science and related risks. The first one is certainly more manageable, easy to use in particular for applicants who are not familiar with scientific and experimental approaches. It is generally made appealing by the use of an eye-catching look, which is more adapted to a generic public mostly composed by very young pupils, whose attention is captured by nice images and graphic applets, the use of which does not require any further scientific explanation.

The other approach is obviously addressed to a more 'specialised' public, e.g. high school students and teachers, and well-trained and guided museum visitors, since it requires a deeper involvement and an active participation of the user in the scientific knowledge process. The game is here to make students and teachers the main actors of the scientific experience, by guiding them along the path of laboratory research practice, based on seismogram observation, measurement, analysis and interpretation.

During the last two decades, this innovative approach has been implemented and carried out in a number of schools, research centres and scientific museums from several European countries, after the pioneering experience of the Princeton Earth Physics Project (PEPP) in the USA (Steinberg and Phinney 2000; Nolet 1993). It uses advanced technologies for seismic wave recording and visualisation or more basic seismic recording instruments and introduces pupils to the analysis of seismograms, measurements of earthquake source properties and the study of seismic wave propagation in the Earth through web-oriented, easy-to-use analysis tools. The ambitious target is to make students, teachers and the general public have an active role in the knowledge process and training them by adopting the 'inquiry-based science education (IBSE)' modern approach of science communication (Banchi and Bell 2008).

Excellent tools and resources for classroom-based experiments which link well with national curricula have been produced by individual groups through national and European funded projects.

- In France, the educational programme 'Sismos à l'Ecole' focused on seismic risk education through a scientific/technological approach. Sixty French schools take part of the education seismology network, by hosting and managing a seismic station, specifically designed and realised for the school. It is a worldwide network with about 12 stations situated in French schools outside France (e.g. China, Australia, EU, Ecuador). Small and large earthquake signals are recorded by French school seismometers, and data are accessible online in real time through a dedicated website (http://www.edusismo.org). In each high school, the teacher's teams are helped by an academic researcher from a close-by university laboratory, acting as a science facilitator.
- In Italy, about 300 students and 10 teachers in different disciplines (physics, natural sciences, informatics and electronics) from 6 southern Italy, high schools

have been fully involved in yearly based EduSeis (Educational Seismology) scholar programmes. During the EduSeis project, the science museum Città della Scienza built and implemented a school lab (SISMALAB), an interactive exhibit for museum visitors and high school classes. In this lab, students and visitors had the possibility to perform seismological data analyses using the EduSeis network database to access data from a real-time seismic station. In 2010, the project restarted in the framework of the seismology@school initiative of the EU project NERA (Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation, http://www.nera-eu.org/) with the initial implementation of five stations in high schools of the Campania region. The project will fully integrate into the real-time, southern Italy ISNet network for active fault monitoring and early warning applications (www.sismoscholar.it). Two of these schools will also be involved in a pilot project for earthquake early warning testing and training in the framework of the European Union project REAKT (Strategies and tools for Real time EArthquake risK reducTion).

- In the UK, since 2005 the school seismology project (UKSSP) has developed a nationwide educational seismology community where teachers and students run simple and inexpensive seismometer systems to be used for detecting earthquake signals, are trained in data analysis and perform several activities on basic physics and earthquake recording instruments. The project has two aims: to make science more interesting for students aged 11–16 and to increase the awareness of geosciences as a potential career and academic discipline amongst students aged 11–18. For these purposes, two distinct requirements for the project were identified: a set of classroom activities to teach students about some basic physics principles but which all had earthquakes as a unifying theme and a simple, inexpensive seismometer system to detect earthquake signals and also to explain some basic physics about how seismometer works.

  The underlying idea of the UK School Seismology Project is doing 'real science with real data' enabling schools to detect and analyse signals from large earthquakes happening anywhere in the world.
- In Switzerland, the programme Seismo@School (http://www.seismoatschool.ethz.ch) started in 2008 and provides an integrated platform for seismic data and general information diffusion, including data from stations installed in Swiss schools and from the broadband national SED (Der Schweizerische Erdbebendienst: The Swiss Seismological Service) network. The Seismo@School platform is a general resource centre for education activities in seismology, which distributes a rich collection of earthquake data, bibliographies, movies, various educational materials and software for seismic data analysis.

These and other European initiatives on educational seismology will merge in the EU project NERA where a specific work package is dedicated to networking school seismology programmes. The ambitious target of the project is to build a dedicated facility for a European-wide school seismology programme, which allows for both the efficient sharing of data across national programmes and the scientific use of the data collected by this distributed infrastructure.

2 Instrumental Development and Projects

Seismology can be used in schools in many different ways. It can be used to teach students about earthquakes and hazards in their local environment, about wave propagation at large planetary scales or about damping and resonance phenomena at local site scales. Academic seismologists have used schools as locations for research grade seismometers in global tomography studies, and primary school teachers have constructed wobbly towers from jelly (Fig. 2). There is no single or correct method of using seismology in schools, rather a broad spectrum of approaches, each driven by different aims and objectives but linked by the enduring power that earthquakes have to capture students' attention and imagination.

Observational seismology in schools has developed along two parallel and complementary strands, one driven by research seismology and one driven by inquiry-based science education. These are reflected in the instrumentation as well as in the educational aims and funding streams of various seismology projects around the world.

In 1979, *Scientific American* published an article describing a simple design for a horizontal pendulum mechanical seismometer made by James Lehman of Virginia (Walker 1979). This seismometer used a garden gate suspension mechanism to create a horizontal pendulum with a natural oscillation period of 12–18 s. The garden gate suspension system for a horizontal seismometer dates back over a 100 years to seismometers developed by John Milne when he was professor of mining and geology in Tokyo. These early seismometers (4a) recorded ground displacement directly using pen and paper charts or by light beams on photographic film (Milne 1888). The addition of electromagnetic sensors detecting ground

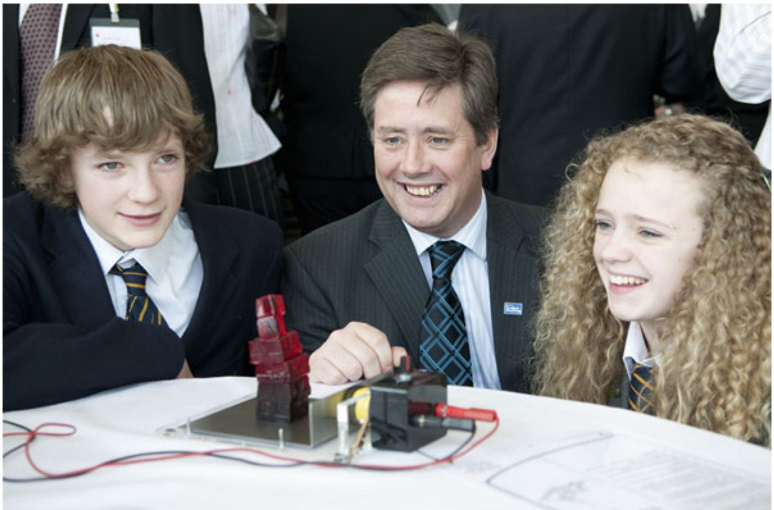

Fig. 2 Jelly towers are used to show how buildings respond to being shaken

velocity enables signals to be easily amplified and filtered. Variations of this simple design have been built by many amateur seismologists, including Stewart Bullen, a science teacher from Hereford in the UK, who built and ran his own seismic station from the late 1980s (Bullen 1998).

In 1994, seismologist Guust Nolet from Princeton University, USA, set up a school seismology network designed to make use of school-based seismometers to record research quality data for tomographic studies. He set up the Princeton Earth Physics Project (PEPP) (Nolet 1993) and worked with instrument manufacturer Guralp Systems to develop a low-cost broadband seismometer system. The result was the Guralp CMG-PEPP seismometer, a force-feedback vertical component seismometer with a flat frequency response in the band 30 s–10 Hz, a 24-bit digitiser and GPS timing system (Fig. 4c).

The idea of using schools as relatively inexpensive sites to locate professional seismometer systems is attractive to seismologists. Unfortunately, the project never really achieved the seismologist's dream of installing thousands of additional research quality stations; there are now only 10–20 school stations in the USA running PEPP seismometers. The advent of large portable arrays run by groups such as PASSCAL (Program for Array Seismic Studies of the Continental Lithosphere) in the USA and GFZ (GeoForschungsZentrum: German Research Centre for Geosciences) and SEIS-UK (the seismic node of the NERC: Natural Environment Research Council) in Europe meant that seismologists could run targeted experiments using hundreds of high-quality stations over areas of special geological interest for fixed periods of time.

In the USA the idea of using a simple mechanical seismometer led to the development of a vertical seismometer, the AS-1 (Fig. 4d). This instrument originally designed in 2000 and built by Jeff Batten was championed by the seismologists John Lahr of the USGS (United States Geological Survey) and Larry Braille from Purdue University.

The AS-1 design proved popular with teachers because of its simple and visually accessible design. This instrument is now the mainstay of a national seismographs-in-school programme in the USA with over 200 schools using the instrument. The US schools network is now supported by IRIS (Incorporated Research Institutions for Seismology), and Alan Jones of Binghamton University, USA, wrote a data-logging and analysis programme for this instrument called AmaSeis (www.iris.edu/hq/sis).

In Europe, school seismology was given a boost in 2000 by an EU-funded programme, EduSeis, which is the acronym for Educational Seismology. This project included the development and distribution of a large number of classroom activities to run alongside the school seismometer stations. In addition to the Guralp PEPP sensor, the European network also used geophone-based seismometers which artificially boost the low frequency response of a standard 4.5 Hz geophone to produce a flat frequency response between 20 s and 50 Hz. With the end of the EU funding, the French schools network managed to continue with national funding and now comprises over 50 schools running semi-professional stations equipped with a data-logger SAGE (Système d'Acquisition Générique pour les écoles), developed in order to realise a robust and extremely simple data acquisition system to be installed in a school (Fig. 4e, f). The digitiser-recorder box is connected to the local computer network of the school using either Ethernet or wireless connection. Each seismological station records in continuous mode the ground motion with a

Fig. 3 The history of instrument deployment in all countries involved in educational seismology projects

Table 1 A list of seismological equipment with its characteristic

	Guralp PEPP force-feedback	Extended geophone	AS-1 mechanical	SEP mechanical
Quality	Very high	High	Very low	Low
Component	Vertical	Triaxial	Vertical	Horizontal
Bandwidth	30 s–20 Hz	20 s–50 Hz	2 s–3 Hz	20 s–10 Hz
Digitiser	24bit	24bit	12bit	16bit
Timing	GPS	GPS	PC clock	PC clock
Simplicity	Very complex	Complex	Very simple	Very simple
Cost	>$1,000 per component	>$1,000 per component	~$500	~$500
Visual appeal	Poor (black box)	Poor (black box)	Good	Good

sampling frequency of 50–100 Hz. Broadband seismometers ensure a high sensitivity in a large frequency band. A GPS unit allows the data to be synchronised with universal time. The timeline of school seismology instrumentation is shown in Fig. 3.

The seismological equipments installed in the different European countries are listed in Table 1, and a fairly complete representation of the instrumentation used in schools is shown in Fig. 4.

The inventory realised in the frame of NERA project on the current status of seismic stations in schools in Europe revealed many 'wrecks' of formerly seismic stations, web pages and e-learning experiments. However, it also pointed out the presence of many operating stations, the data of which are currently available or can be easily included in a comprehensive database.

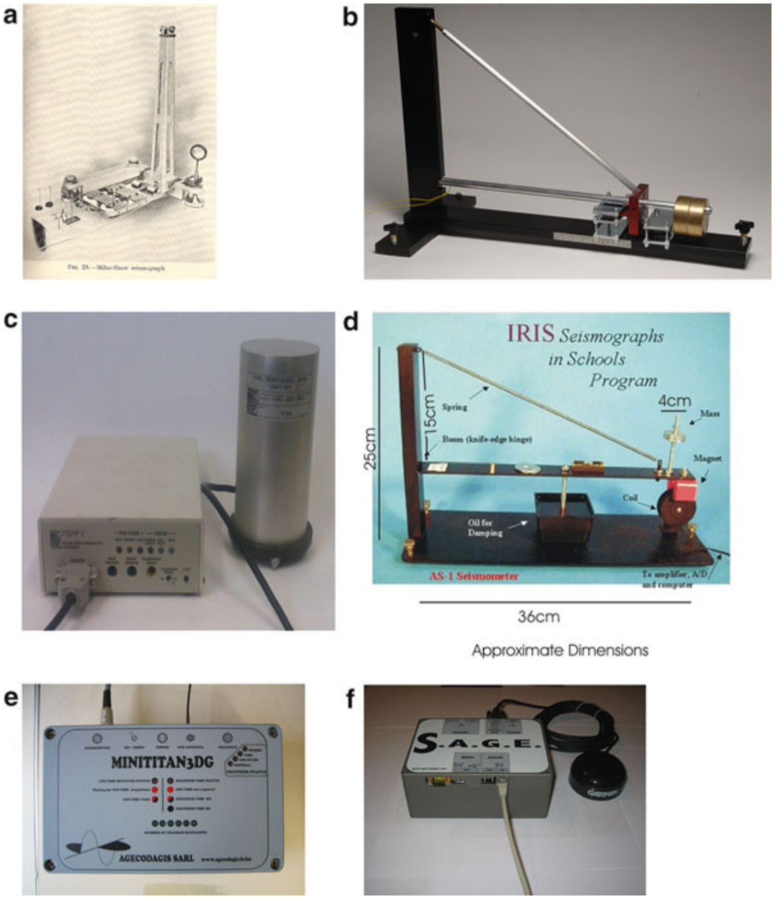

Fig. 4 (**a**–**d**): An overview of different school seismological instrumentation: (**a**) nineteenth-century Milne Seismometer, (**b**) 2006 UK SEP school seismometer, (**c**) 1996 Guralp PEPP seismometer, (**d**) 2000 AS-1 seismometer and (**f**) Agecodagis SAGE seismic system

At a first glance, the map of the seismic stations operating in schools in Europe shows a clear unbalancing of their number in the western region with respect to the eastern side (Fig. 5).

3 Implementation, Outcomes and Evaluation

3.1 France

The network ‘Sismos à l’Ecole’ numbers around 60 stations installed in metropolitan France, the overseas departments and territories and few French high schools abroad. It is the outgrowth of an experiment conducted in the south of France aimed at

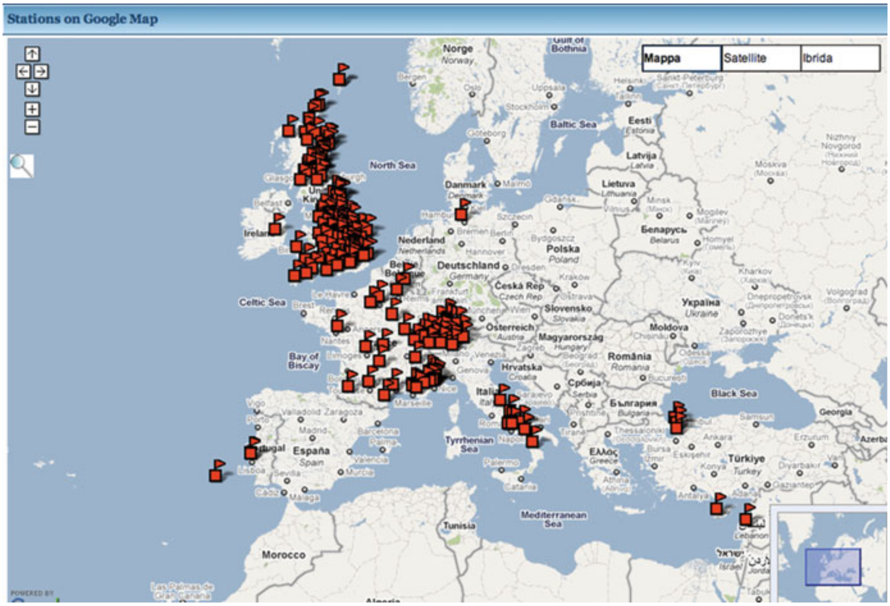

Fig. 5 Distribution of seismic stations in Europe

studying the feasibility and the pedagogical interest of installing a seismometer within a school. The project was first implemented over a period of 10 years (1996–2006) and involved a close partnership between the Conseil Général 06, the Rectorat of Nice district and the Géoazur research lab (Virieux 2000). The results from the deployment of five stations showed that it was possible to record high-quality signals in a school environment. Teachers revealed a number of positive points from this experience: the students were enthusiastic to perform measurements, the online database was easy to access and use, the students were encouraged to work independently by taking responsibility for the management of the seismic station, and finally, the experience demonstrated the importance of regular interactions between school teachers, student and scientists from the closest Géoazur laboratory in French Riviera. Since 2006, the programme 'Sismos à l'Ecole', which is part of the broader project 'Sciences à l'Ecole' supported by the French ministry of education, has extended the educational seismological network throughout the country. Following a call for proposal, new schools were selected according to the quality of their pedagogical projects in order to build an active network. Now, 60 stations record in continuous mode the ground motions in French schools, either in metropolitan France or abroad (Fig. 6a). Each school is linked with a volunteer seismologist from a nearby university laboratory. The seismologist must build a relationship of trust with the educational team that will call on him (or her) to address technical or scientific issues and also to occasionally participate to activities in the classroom. The network's success is largely due to the dynamism and cohesion of its teams.

Fig. 6 (**a**) Map of the 60 real-time seismological stations of the French ‘Sismos à l’Ecole’ network (Data from all stations are accessible freely via the Internet through the website www.edusismo.org), (**b**) Building scientific know-how and some examples of seismo-tools. The seismo-cookbook

c

Fig. 6 (continued) gathers activities and experiments that can be made by students from 11 to 18 years old. A toolbox has been constructed to help teachers and scientist to present different parts of seismology, (**c**) The educational session in ESC (European Seismological Commission) 2010 meeting in Montpellier. Students, teachers and scientists sharing experiences

The school curriculum has several important aspects, placing large emphasis on new communication technologies: the scientific content (instrumentation, earth dynamics and geophysics), the educational dimension (making aware about seismic risk) and the regional, national and international dimensions (networking schools). The students observe, measure, compute and discover in order to understand better natural phenomena (Fig. 6b).

Within the framework of courses in earth and life sciences, physics, technology and geography, there are various pedagogical suggestions proposed for the curricula of French high schools concerning the measurement of a physical parameter, the knowledge of the geological environment, the understanding of the complex mechanisms of the internal geodynamics and the notion of environmental risk.

In all these activities, transversal approaches are encouraged, measurement, observation, model building and investigative thinking, to grasp the scientific concepts related to geosciences and physics. This building of scientific know-how is essential to education, information and awareness on environmental risks.

The teachers (about 110) and researchers (about 20) who are involved in the 'Sismos à l'Ecole' network follow a regular training programme and attend meetings, one each year or every 2 years. They have proposed, coherently with the objectives of French Ministry of Education, several scientific topics that can be developed in the classrooms with students.

The topic dealing with ‘sensors’ is one of the most important. The measurements of a physical quantity by a sensor (e.g. the measurement of ground motion versus time) can be investigated, using sensors from the seismological station or sensors developed by students. Several aspects of basic science are tackled, including the definition of frequency, bandwidth, fidelity, repeatability and the robustness related to the linear oscillator behind the sensor.

The topic dealing with ‘data’ arises naturally. The analysis of recorded signals leads to various activities, including activities on waves, a key concept in the modern society as radio, TV and Internet use electromagnetic waves massively. Travel times, wave speed and source location through triangulation are typical concepts a student can easily manage without getting into sophisticated mathematical tools.

The ‘earth sciences’ topic is obviously central to teaching of natural sciences. Possible activities include geographical mapping through the presentation of data collected from the schools, the discussion of seismic hazard either on a global scale or a local scale and the presentation of different seismic signatures such as the Benioff subduction zones or the Moho discontinuity separating the Earth crust from the mantle.

The ‘risk’ and ‘hazard’ topics come naturally after these various speculations or analyses. Based on seismic records, students can illustrate through practical models the notion of intensity, building resonance, earthquake-proof rules of construction and the induced effects of a tsunami on coastal zones. With many national initiatives, this topic will become more and more important in educational training.

All these practical activities have been brought together in a single workbook and some models (Berenguer et al. 2009a, b).

3.2 The UK

In 2005, inspired by the success of school seismology networks set up and running in various US states using AS-1 and Guralp PEPP seismometers, the UK started work on a school seismology project (Fig. 7) (Denton 2009).

The UK project arose out of a need to improve participation rates in school sciences, especially physics, once students were able to choose subjects to study (and which ones to drop) at age 16. In the previous decade, the number of students studying physics had dropped by 50 %. Universities running geosciences degree courses at undergraduate or postgraduate levels were struggling to recruit good students to their courses, and the major employers of geosciences graduates in the UK were suffering recruitment problems as a consequence.

Initial discussions with small focus groups of ten secondary school science teachers at a workshop organised by Leicester University led to a number of conclusions: (1) the use of practical observational seismology in a UK school environment was thought to be an excellent context for teaching about a wide range of basic science topics. (2) Given the choice between a research quality seismometer in a ‘black box’ enclosure and a simple mechanical sensor with a visually open design, the teachers all preferred the simple mechanical design.

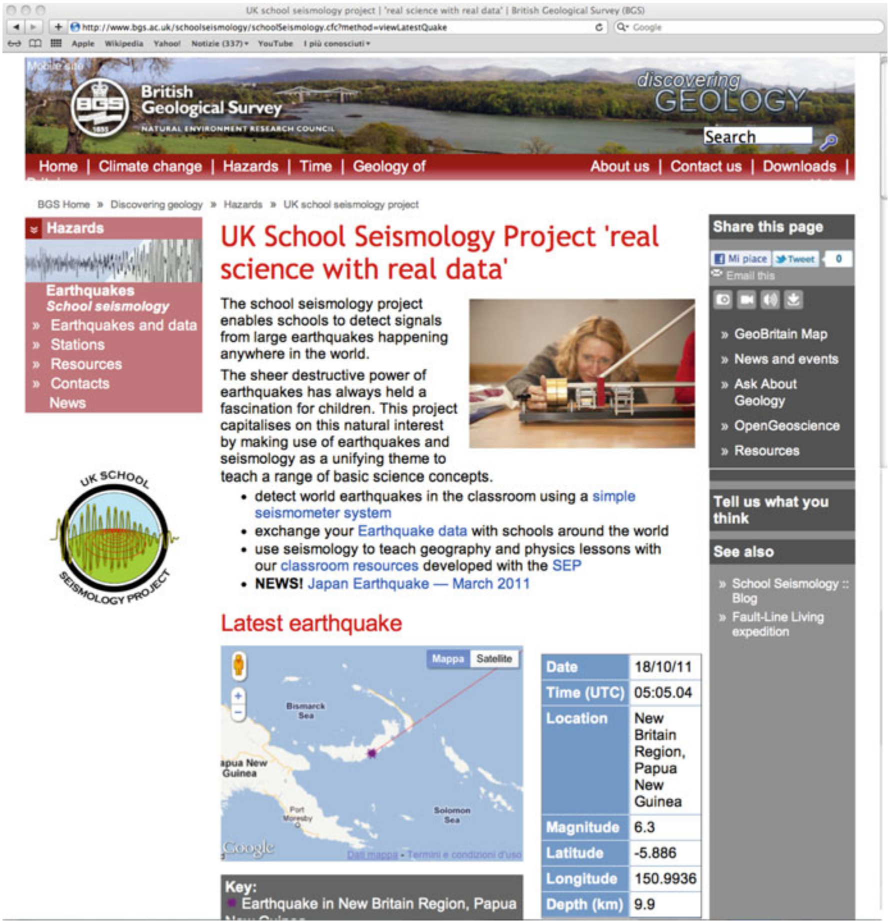

Fig. 7 The website of the UK school seismology project http://www.bgs.ac.uk/schoolseismology

Each year in the UK, a seismometer station located in an urban environment is likely to detect above background noise less than ten local earthquake signals (from the UK or Europe) but over 50 teleseismic earthquakes, mostly from the Pacific rim. In order to be able to detect the large-amplitude surface waves with peak frequencies around 0.05 Hz from these teleseismic events, a simple mechanical seismometer needs to have a natural period of 20 s or longer.

The UK school seismology instrument was finally chosen as to be a version of the garden gate suspension horizontal pendulum system, designed and manufactured by engineers from the Science Enhancement Programme SEP (www.sep.org.uk), a charity-funded organisation dedicated to improving science education in schools.

The SEP school seismometer system (complete with amplifier/digitiser electronics package) was designed to be compatible with the existing AmaSeis seismic data-logging and analysis software and was launched in 2007 together with a tried and tested set of classroom science activities that all had seismology and earthquakes as a linking theme (Denton 2008). The British Geological Survey manages the UK school seismology project (www.bgs.ac.uk/ssp) by promoting the project to teachers and running training workshops in how to use the resources in partnership with university earth science departments around the country (Imperial, Leicester, Keele, Leeds, Plymouth, Bristol, Liverpool, Derby, UCL, Royal Holloway, Portsmouth, Edinburgh, Aberdeen, Cardiff).

3.3 Italy

Following the successful experience in the USA of the Princeton Earth Physics Project (PEPP) in 1996, Italy installed the first seismic station of the EduSeis project 'MSNI' (*M*useo della *S*cienza *N*apoli *I*talia) at the Science Centre 'Città della Scienza' in joint cooperation with the University of Naples 'Federico II'. In Italy, from 1997 to 2002, more than ten EduSeis stations were installed in high schools and at research centres in central and southern Italy, in particular at the Mt. Vesuvius volcano landscapes (Bobbio and Zollo 2000). The seismic stations were installed inside buildings, with the sensor preferably deployed at a ground or underground level while the acquisition PC was hosted in the informatics lab.

All the elements of the station were specifically designed for educational purposes and operating by the students and teachers themselves. The EduSeis network was made up of seismic stations that may record local, regional and world seismic events. The seismic stations are equipped with different acquisition systems and sensors used as a standard in scientific/monitoring seismic networks.

Special software applications have been conceived to make them easy for pupils to work on seismological data. Seismic recordings can be visualised and analysed with the Java SeisGram2K software developed by A. Lomax (www.alomax.net). With this applet, the signal can be zoomed and displayed together with the records from several other stations. In addition, different seismic wave times can be picked, and different band-pass filters are available to improve the seismogram analysis.

The basic idea of the EduSeis project was to use a network of seismic stations installed in high schools and related activities of data analysis as an efficient and pervasive tool for teaching, learning and informing about the earthquake origin, its destructive effect on the environment and the actions needed to mitigate seismic risk (Cantore et al. 2003).

Within this framework new approaches were experimented for providing information on seismology and seismic risk addressed to the general public and to high school audiences. These were realised through an interactive seismological lab (SISMALAB) operated and maintained by the scientific museum 'Città della Scienza' in Naples and through an *e-learning* environment in a high school located close to the Mt. Vesuvius volcano.

SISMALAB was a school lab and interactive exhibit (about 30 m^2), equipped with six multimedia graphic stations and an adjacent meeting point room for real-time teaching/learning activities for museum visitors and high school classes (Fig. 8a). Here people can experiment with seismological data analysis and learn about earthquake origins and occurrences, volcanic eruptions and earth sciences in general. A carnet of activities designed for the students of secondary and high school were specifically created for SISMALAB, thanks to a permanent staff formed by school teachers, museum personnel and young researchers from the University of Naples. The SISMALAB activities were differentiated by age for groups of students and visitors. Each group was involved in using software for processing seismic data. This experience revealed to be SISMALAB, an efficient tool to raise curiosity and stimulate students to ask questions and work directly on seismological data recorded at the different stations installed in schools (Cantore et al. 2004).

In the framework of this initiative, two related editorial activities started aimed at the diffusion of the EduSeis project: an information booklet entitled 'Earthquakes – How, where, when, why…' and a bimonthly electronic newsletter (Cantore et al. 2005).

The e-learning model experimented during the project was built on the EduSeis concepts and educational materials and based on the computer-supported collaborative learning (CSCL) that is an innovative method for teaching and learning which adopts the modern information and communication technologies. This kind of learning is characterised by the sharing and construction of knowledge amongst participants using technology as their primary means of communication or as a common resource (Stahl et al. 2006). The EduSeis educational activities (earthquake location, magnitude estimate, seismogram analysis, etc.) which are mostly based on web and net communication tools are suitable for this kind of experimentation. Ten teachers from different disciplines and 50 students of technical high school I.T.I.S. 'Majorana' (Naples) were involved in a cooperative e-learning experiment, using an informatics platform and the *jigsaw* method (Clarke 1994), in which students worked in small groups (communities) where each member evolved gradually from a fellow learner to a teacher and finally to a 'scientist' (Fig. 8b) (Bobbio et al. 2007). The learning process was assisted and supervised by teachers. The evaluation of experiment results provided useful insights on the contents and the educational value of EduSeis modules and activities.

In Italy, another project was carried out in the framework of the educational activities on earthquakes: EDURISK (EDUcation to RISK) (Camassi 2006; Solarino 2009). Although the targets and goals are very similar to the EduSeis project, the activities included were different and diversified in ways and forms of implementation. The EDURISK project is currently designed for the whole range of students' ages from primary to high school. It carries out a wide variety of activities, ranging from exhibitions to lessons in schools and visits to the National Earthquake Centre or museums run by INGV (Istituto Nazionale di Geofisica e Vulcanologia). During almost two decades of activity, the project has edited and printed many books and produced several multimedia items that are specifically designed to foster, nurture and enhance knowledge. The goal is to either explain the science behind the natural phenomena or to increase the preparedness of future citizens towards them. However, the most important activity is developed for and with the help of teachers. Instead of directly informing single groups of students, the researchers of EDURISK staff involved teachers. In practice, the teachers joining the project undertake to fit

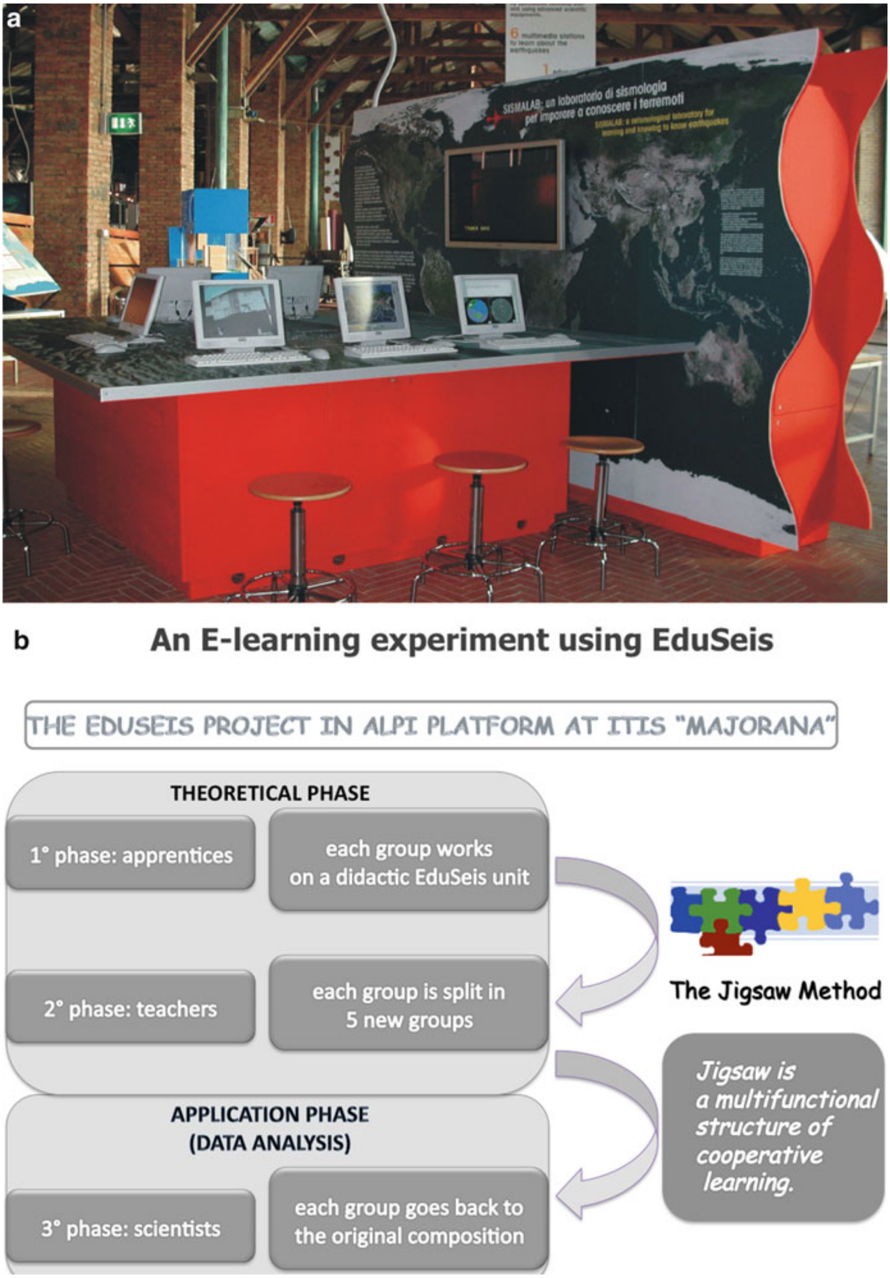

Fig. 8 (**a**) The SISMALAB at the Science Center of Città della Scienza in Naples, (**b**) A scheme of the e-learning experimentation at ITIS Majorana (Somma Vesuviana, Naples). In the first phase, each group became the experts of a topic on seismology; in the second phase, the groups were split and each student could be a teachers for the members of their new group; in the last phase, the original groups were reassembled and the students, having acquired a deeper knowledge on seismology, were considered as 'scientists'

the EDURISK prototypes within their curricular activities for at least one academic year, at the end of which they assess their effectiveness, suggest alterations/improvements and provide additional feedback.

3.4 Switzerland

Through seismology, the programme *Seismo@School* tries to make significant contributions to science education in the understanding of the Earth system and complexity.

The *Seismo@School* network consists of seven seismic stations installed at schools across Switzerland. This number has been increased to 15 at the end of 2011. The first stations of the SED (Swiss Seismological Service) were equipped with short period seismometers that provide high-quality waveform data for the regional seismicity. Future stations will be equipped with standard strong-motion sensors, which are routinely used by the SED national network. They provide at the same time good data quality for the school network and valuable additions to the national monitoring efforts of SED. Stations are installed in quiet basement rooms in school, to avoid as much as possible disturbances induced by human activities.

The school network database contains the seismic waveforms recorded by 12 stations of the Swiss national seismic network operated by the SED to allow comprehensive analysis of the recorded seismic events. For educational activities, schools also make use of other stations like the one component SEP seismometer system or the Stanford accelerometer, Quake-Catcher Network Sensor (http://qcn.stanford.edu/sensor/), which are very useful for classroom activities.

The cornerstone of the educational activities within *Seismo@School* is the project website (www.seismoatschool.ethz.ch). This open-access website provides access to both real-time streams and data for selected seismic events. The website also makes available a rich set of software packages for data display and analysis, specifically developed for schools' needs. Analysis capabilities of the software include travel time calculations, phase picking (onset determination), earthquake location and location process visualisation, amongst others.

Background and in-depth information on the school project and on specific scientific topics are also available from the website as well as all educational materials (books, classroom activity suggestions).

The activities in schools range from participation in the installation and operation of the seismic school stations to classroom experiments involving students of different ages and levels. The educational material contains books, posters, experiments and an earthquake simulator. As seismology is not covered in standard education of teachers, and earthquakes are not usually part of the school curricula, the SED developed a training programme for teachers comprising three steps. The first step '*Four days formation at school*' aims at providing an in-depth explanation and training on the seismic station installed at the school and a familiarisation with the tools and data available on the Seismo@School website, to foster enhancement of seismology and earth science education in schools. The second step involves teachers' workshops at ETHZ (*E*idgenössische *T*echnische *H*ochschule *Z*ürich: Swiss Federal Institute of Technology Zurich). These workshops comprise lectures by SED researchers on seismological topics, combined with visits to the *focus*Terra exhibition and the earthquake simulator. They are organised to provide professional development experiences for educators. Teachers will become active participants learning through demonstrations, computer modelling and hands-on activities. For example, in the area of seismology, teachers are trained to handle the seismometer instructional materials, to access seismic data via the web server and to access and use all the programmes available to explore and analyse the data. As a last step, national and international seminars are organised to facilitate good connection between teachers (teachers' network around Switzerland and Europe) and to promote exchanges with researchers. The experience and feedback during these events have confirmed that such conferences and workshops are really successful and represent the best way to share experiments and knowledge (Fig. 9a–c).

a

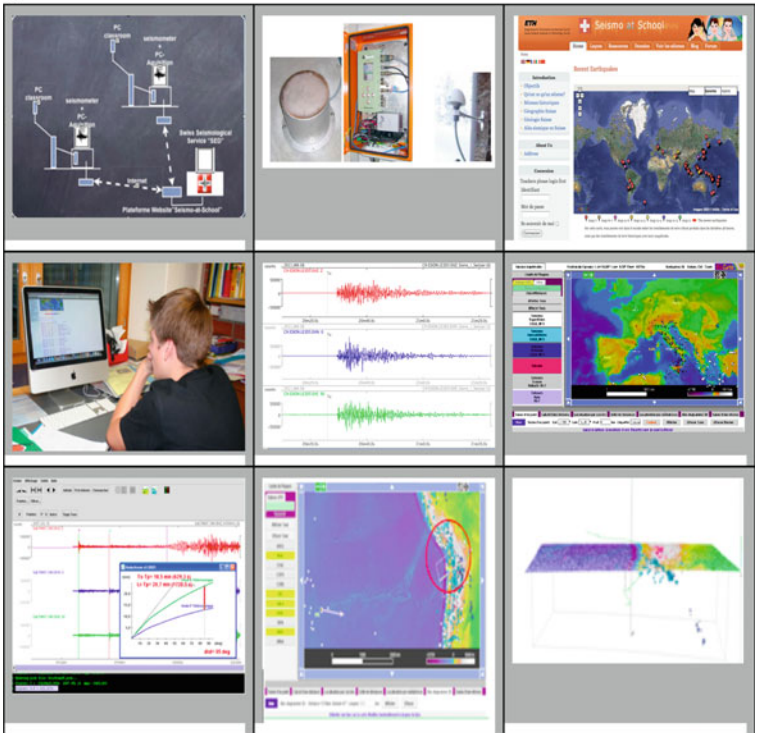

Fig. 9 (**a**) Scheme of the school network in Switzerland. Example of seismometer and GPS installed in school. Website Seismo@School connection for students working with data and softwares developed for them, (**b**) Preparation and installation of SEP seismometer by students, during physics lecture, (**c**) Activities and booklet developed for schools, earthquake simulator room, conference for schools in Zürich, training the teachers, students' exhibition in national and international conferences

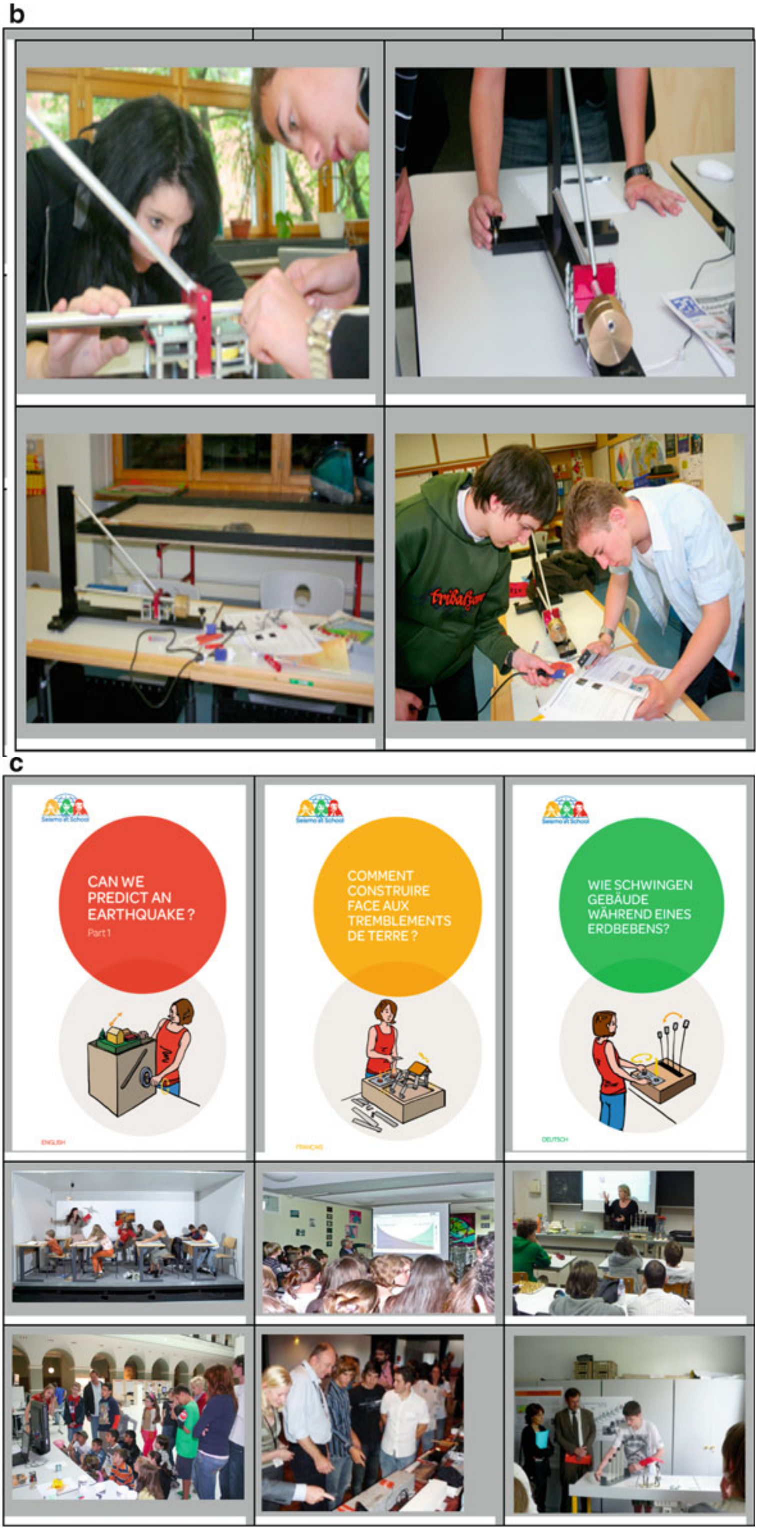

Fig. 9 (continued)

3.5 Cooperative and Interregional Educational Activities in Seismology

Unlike the pioneer initiatives, which were involving single countries, the most recent educational projects share experiences, skills and data amongst several nations. The exchange is mainly supported by and operated through the availability of fast and reliable Internet connections, but often experiences and common activities are designed in dedicated meetings where teachers and students from different countries gather and discuss.

The project O3E (Observation of the Environment for Education purposes at School) (Berenguer et al. 2011), recently concluded after 2 years of activity, established a network of schools amongst the participating countries of France, Italy and Switzerland. The project, financed by the EU under the ALCOTRA programme, was born to promote a responsible behaviour of citizens against natural hazards

The aims include:

1. Promoting the applied sciences and new technologies
2. Gathering students, teachers and scientists in a network developing the sense of the autonomy and the responsibility of choices in young people
3. Reinforcing and developing relationships with regional partners of the educational and university fields
4. Supporting a rational awareness for the prevention of the natural risks that can make the difference during the event in terms of safety

About 30 schools located in the territories included in the ALCOTRA programme were equipped with seismometers and/or weather stations of educational vocation. Teachers and students were given the responsibility of the data collection and instrument maintenance. Data were shared with the entire educational community through dedicated servers on a common web page (http://o3e.geoazur.eu/) and served as the basis of numerous experiments and activities.

During the first stage, researchers and technicians, both from academic and nonacademic institutions, provided assistance for the installation of the instruments, to set up the data transfer and gave introductory lectures about the scientific and technical aspects of the project. A few multimedia and printed products were prepared and distributed within the project, in some cases to be used as a guide for common experiments. Finally, some digital documents and software were made available in the 'documents' section of the web page.

However, soon schools were let free to design and conduct their own experiences, which are of course finely tuned to the actual environment and hazards of the country and territory. The results of these activities have been discussed in a final, comprehensive meeting (http://ftpaster2.unice.fr/o3e/images_docs/110204_104630-Actes_complets.pdf).

There are many outcomes of the project that deserve mention. In most cases they are directly linked to the philosophy that leads the project and are innovative with respect to many previous other educational programmes. In fact, the presence and maintenance of an instrument introduce problems and needs to which only professional are used to; adapting school life to these aspects introduces in new attitudes.

Amongst the main consequences, students and teachers were required to check the discrepancies between the real data and the information disseminated by the media, developing and improving their critical skills. The need for good and reliable data made them understand the difficulties behind such a task and especially the errors and uncertainties on measurements and models. Finally, the students could identify and understand the main natural hazards of the places where they lived and their potential impact. All these aspects may have concurred to form citizen better prepared to face emergencies and able to disseminate correct and sound information.

4 Implication for Wider Practice and Conclusions

The main initiatives to introduce seismology in European schools and use it as a vehicle for a multidisciplinary teaching about earthquakes and Earth dynamics in general have now been active for more than two decades. At the same time, teachers have been able to estimate the contribution of such actions in their practice of teaching.

Now, it is possible to draw up a first assessment of these actions.

A recent survey on the French school network collected the opinion of about 50 teachers and educators on the programme led since 2006 in France (http://www.edusismo.org/docs/news/120103_125618/resodusismo_2011.04.pdf).

The general opinion is that, in 10 years, the set-up seismological equipment and analysis tools (seismometer, data online, models) quickly have become established in the landscape of the classroom and are more and more used for new practices of teaching natural sciences in high schools. They are also the mainspring in the creation of scientific labs where students lead investigation projects by themselves.

In earthquake-prone areas, seismological experimentation at schools is also a way to increase the awareness on seismic risk and earthquake effects of students and, through them, of their parents. This is the case in southern Italy, where earthquakes and volcanic eruptions represent the most relevant natural hazards hanging dangerously over the population. The experience of educational seismology at the Science Centre ‘Città della Scienza’ in Naples is exemplary. Thousands of elementary and high school students have visited the earth science section of the museum, having the opportunity to play with and learn from seismological tools running on the interactive exhibits in the museum and using the SISMALAB laboratory, a multimedia, open space for educational activities in seismology. The successful participation of students and museum visitors clearly indicates that innovative teaching approaches based on web and net communication tools are well adapted to communicate and inform about natural hazards.

Another key point is the scientific support of researchers and the need to establish strong links between teachers and researchers. The implementation of educational seismology projects in schools has been carried out in the framework of joint projects where schools, research centres and universities participate in partnership. The role

Table 2 A list of strong points and weak points in the application of educational projects in the school system

Strong points	Weak points
'Learning by doing' approach applied to earthquake and wave propagation phenomena	Difficulty to involve teachers at zero-cost, in extracurricular activities
Enhancing and stimulating the cooperative work	The management and maintenance of the seismic station needs a continuous effort and engagement
Making students acquainted with the seismological laboratory practice, data	Small flexibility to use school time and spaces and insufficient resources (informatics, tools, instrumentation)
The simplicity and cheapness of equipment has allowed its distribution to a very large number of schools, the overall aim being to change the perception of geosciences in schools across the country	With such a large number of schools, it is difficult to provide detailed one-one support for teachers with problems. The simplicity of the equipment means that the data cannot be used for scientific research

of researchers is to accompany and support teachers in their discovery, formal activity development and training on seismological tools. The collaboration between researchers and teachers on the development of seismological activities is crucial and demands for a continuous and mutual effort to immerse oneself in the shoes of the other, sharing the different languages, scientific backgrounds, levels and tools of scientific communication. The effective interaction between school and academia staff is the key for the success of these educational initiatives, and to establish a good, convivial and enthusiastic working team is likely the first but most important task of an educational project in geosciences. This is not always an easy task, since in most cases these activities are carried out by researchers and teachers on a voluntary basis not being part of school curricula or funded research programmes.

We should not neglect the problems and difficulties of the application of these educational projects in the school system, in particular the need for a big involvement of teachers and researchers. The main difficulties in the development of the projects are related to the teachers' involvement at zero-cost outside working hours, the small flexibility in school time and space and the insufficient scholastic resources (informatics, tools, lab instrumentation) (e.g. Table 2).

At any time and for any of the European experiences, the website is the central tool of the educational seismology programme, and a well-designed website strongly facilitates interactions and data/information diffusion. The website is the place where the screen of a school seismological station is displayed (simple link to the school seismometer) either to visualise the real-time recorded data or to access and analyse the archived data. The statistics of the French 'Sismos à l'Ecole' websites confirms this trend for Internet users (6,000 visitors per month access the French website). Teachers and students can also find and download hands-on educational activities or scientific documentation or other material to support the teaching of earth science and seismology in particular.

The publishing of the resources (seismograms, mappings, hands-on activities) demands particular care because it addresses the whole educational community: students, teachers and the general public. The website must be able to offer data quickly, simply, and in high-quality format. The elaboration of such sites still remains a big challenge.

The new vogue is to open the website to social media and blogs, transforming it from a static archive of information to a virtual place where users can debate, ask questions, comment, tweet and share photos, videos and educational experiences on earthquakes and their impact on the environment and society. This approach generalises the concept of an educational geoscience website making it an e-platform for science communication and multimedia data sharing, where researchers, teachers, students and education operators can interact and constantly be kept informed of ongoing activities and relevant events.

Finally, all of these ‘seismology at school’ initiatives rely on the concept of school networking. A collaborative network is created through the publication of data on the website, the organisation of training courses and the communication of actions led in different schools. Also, the exchange and publication of data collected by individual schools and shared through the Internet are essential.

The concept of ‘networking’ is intrinsic to the seismological observation: a complete description of seismic wave propagation or the determination of earthquake source parameters cannot leave out the use of many sensors, organised in a seismic network and deployed at different azimuths and distances from the source. This facilitates the process of ‘networking’ schools that are involved in an educational seismology project since the earthquake and the related seismic wave observations from a seismic sensor hosted in a school can (must) be shared to get the complete description and interpretation of the natural phenomenon. Examples include the process of locating an earthquake, which uses the P- and S-wave arrival times read at different stations to compute the event coordinates, depth and origin time or of estimating the subsoil apparent seismic velocity, needing measurements of arrival times from stations located at increasing distance from the source.

We can usefully wonder about the main directions to be followed, even to be developed, for future programmes of educational seismology. Trying to get the schools involved and actively participating in scientific projects that use data collected by school seismographic stations is the ambitious target of the next generation of ‘seismology at school’ programmes at a national and pan-European scale. This will require a special effort to improve the technological level of instruments deployed in schools in addition to setting up a network data management system resembling the professional ones used by seismological agencies. But it also demands a specific training activity for teachers and students to make them acquainted with the seismological laboratory practice on instrument maintenance, data control and validation, data analysis and modelling, a quantitative assessment of uncertainty and resolution.

The EU project NERA may be a possible answer for a new step in the national educational seismological programme in Europe (Table 3).

Table 3 A list of european seismological projects with corresponding websites

Projects	Website
NERA (*N*etwork of *E*uropean *R*esearch Infrastructures for Earthquake Risk *A*ssessment and Mitigation)	http://www.nera-eu.org
NERA WP8 (ITALY)	www.sismoscholar.it
EDURISK	http://www.edurisk.it
Seismos à l'École	http://www.edusismo.org
UK school seismology project	http://www.bgs.ac.uk/schoolseismology
Seismo@School	http://www.seismoatschool.ethz.ch
O3E (Observation of the Environment for Education purposes at School)	http://o3e.geoazur.eu/

It plans to share the data recorded by each school network, to share also the experiences of teachers and/or students. New computing tools are to be implemented to improve this interconnection of school seismic networks and programmes. Training workshops, gathering teachers from various countries (summer schools for teachers), will contribute to these exchanges. It is at the very last a desire of the teams involved to develop more contacts between schools in Europe.

Overview

Background and Motivation

- During the last two decades, across Europe, several educational projects in earth science were developed and are ongoing in a variety of situations and national contexts with the aim to disseminate meaningful information about earthquake risk and actions, which can be undertaken to reduce or mitigate its effects.
- The seismology may represent an efficient communication vehicle for teaching a wide range of basic science topics through experimental practices and educational activities.
- The seismology is an effective tool to raise in young citizens the awareness about the earthquake risk and possible mitigation actions.

Innovations and Findings

- Innovative teaching approaches based on web and net communication tools are well adapted to communicate and inform about natural hazards.
- The collaboration between researchers and teachers on the development of teaching tools on seismology is an innovative aspect in educational context and demands for a continuous and mutual effort to immerse oneself in the

(continued)

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shoes of the other, sharing the different languages, scientific backgrounds, levels and tools of the scientific communication.
– We find that the proposed approach stimulates the involvement of students having an active role in the knowledge process by observing, experimenting and measuring the natural phenomena using web-oriented and accessible data analysis tools, which provide a direct access to the seismological laboratory practice.

Implications for Wider Practice

– The installation inside the school of the seismic stations, specifically designed and realised for educational purposes, and the use of web-oriented and accessible data analysis tools have introduced the students to the seismological laboratory practice.
– A good implication for wider practice could be the experimentation of the e-learning model built upon earthquake science and educational materials and based on the Computer Supported Collaborative Learning (CSCL), an innovative method for teaching and learning which adopts modern information and communication technologies.
– Goals include the development of a new generation of educational geoscience websites making them as e-platforms for science communication and multimedia data sharing, where researchers, teachers, students and education operators can interact and constantly be kept informed of ongoing activities and relevant events.

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EARTHTIME: Teaching Geochronology to High School Students in the USA

Britta Bookhagen, Noah McLean, Robert Buchwaldt, Matthew Rioux, Francis Dudás, and Samuel Bowring

1 Introduction

1.1 Why Teach Deep Time in School?

There is widespread recognition among scientists and education policymakers that student engagement in science must be improved. In order to maintain our technological standard, we need to ensure a scientifically literate society and continued contributions by competent scientists (American Geophysical Union 1994; National Science Foundation 1996; National Research Council 1997; National Science Board 2002, 2003). Geologic time ("Deep Time") is an important concept in geology, as already established by Hutton 1788 and Lyell 1830, giving a logical timescale to many Earth processes and events. Understanding the timing and rates of geologic processes is critical for understanding such diverse topics as the age and assembly of the Earth, plate tectonics, the timing and causes of mass extinctions, and the recurrence rates of volcanic activity and other natural hazards. Because geologic time and geochronology integrate elements of chemistry, physics, biology, and mathematics, teaching "Deep Time" provides an opportunity to introduce students to a key scientific concept that integrates knowledge from a diverse range of disciplines.

Research has demonstrated that several common preconceptions in science should be individually targeted. Project 2061, an initiative of the American Association for the Advancement of Science (AAAS, 2009), was founded in 1985 to advance literacy in science and has included more than a decade of research and development on preconceptions in science. Philips (1991) confirmed and summarized some earth science preconceptions that address time and time measurement

B. Bookhagen (✉) • N. McLean • R. Buchwaldt • M. Rioux • F. Dudás • S. Bowring
Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA, USA
e-mail: britta.bookhagen@gmail.com

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(e.g., mountains are created rapidly, all radioactivity is man-made, dinosaurs and cavemen lived at the same time). Research has also demonstrated that university students have difficulty grasping extended timescales, on the order of millions of years (DeLaughter et al. 1998; Libarkin et al. 2007). It is generally accepted that students create conceptions about the world from their experiences (e.g., Lederman 1992), and "Deep Time" is not something that one can experience.

The Global Science Literacy (GSL) states that the understanding of "Deep Time" is one of the central constructs of the geosciences (McPhee 1981; Mayer 1991a; Rudwick 1992) and forms one of the seven basic science understandings that construct science literacy (Hurd 1958; Clary et al. 2009). Geologic time is described in the GSL as a "key concept that spans natural science" and a "core element or critical barrier" (Trend 2002). The Earth Science Literacy Initiative (ESLI 2009), funded by the US National Science Foundation, developed a framework of underlying principles in earth science and identified the age of the Earth as the Big Idea #2 in earth science literacy. Many others agree that understanding "Deep Time" can change people's view of nature and humanity's role in it (e.g., Mayer 1991b; Lederman and O'Malley 1990) and that "Deep Time" is a key concept that affects other subjects (Dodick and Orion 2003). In addition, several books (e.g., Gould 1987; Haber 1959; Gorst 2001, and references summarized by Dean 1981) and papers address the topic of "Deep Time" (e.g., Patterson et al. 1955; Ault 1982; Trend 2001; Dodick and Orion 2003; Clary et al. 2009) and state its importance. Thus, teaching high school students about geochronology provides an opportunity to introduce students to a key concept of geology, address pre- or misconceptions, and improve science literacy. Toward this goal, we developed a teaching module to introduce high school students to how geologic time is measured and used for understanding Earth processes.

Following Piaget's constructivist learning theory (Piaget 1967), inquiry-based teaching and hands-on activities have been shown to facilitate learning complex topics (e.g., Tobin 1990; Mintzes et al. 1998). In addition, a recent study showed that improved collaboration between research scientists and K-12 (primary and secondary) educators enriches student experiences using otherwise unavailable resources (Gosselin et al. 2003). For teachers in the USA, there are abundant opportunities for hands-on activities and field trips in science subjects such as biology and chemistry, but we observe a dearth of similar opportunities in the geosciences, which are usually taught as elective sciences class in schools; the US National Science Teachers Association (NSTA) has been trying to elevate earth science in parity with physical and biological sciences. Field trips can be a great way to engage students with different topics, but due to time and money restrictions, they are not always feasible. Our feedback from teachers suggests that ready-to-use lesson plans in earth sciences would be greatly appreciated and could be another way to strengthen the application of earth sciences in school.

To create a productive education module on geologic time, we developed, adapted, and tested strategies for teaching U-Pb geochronology in different settings in the Greater Boston area, USA, over a 2-year period. This project was part of the EARTHTIME outreach initiative and was primarily developed by professors, postdocs, researchers, and graduate students in the MIT isotope lab. The goal of the project was to build theoretical and hands-on exercises to introduce students ages 14 and older to the concepts of "Deep Time" and geochronology. The modules we developed focus on introducing students to the techniques used for measuring geologic time and how these techniques can be used to study Earth history. To test the effectiveness of the teaching modules, we utilized multiple qualitative and quantitative datasets collected through questionnaires for students and science teachers. In this chapter, we will focus on data collected from 144 participants from one school, where pre- and post-tests were conducted to measure learning outcomes.

The purpose of this chapter is to describe the different parts of the outreach project and to use this example to qualitatively assess the effectiveness of our hands-on approaches in the classroom.

1.2 Description of the EARTHTIME Initiative

EARTHTIME is a scientific initiative aimed at sequencing Earth's history through international cooperation and collaboration (http://www.earth-time.org/). The initiative is supported in the USA by the National Science Foundation (NSF) and in the EU under the Framework Program 7. The need for this organizational structure to facilitate a better communication between geochronologists, stratigraphers, and paleontologists was recognized in 2003, and the aim of the EARTHTIME decade (2006–2016) is to create better tools to constrain Earth history through high-precision geochronology. A key component of the EARTHTIME initiative is educational outreach, with the goals of (1) developing educational tools with exercises and teaching material that provide students with multiple opportunities to explore difficult concepts in earth science and integrate new learning into their knowledge framework and (2) providing opportunities for students to interact with scientists and gain an understanding of how scientific research is done.

The MIT isotope laboratory has played a leading role in the EARTHTIME outreach initiative. The isotope lab specializes in the application of geochronology for understanding the rates and timing of geologic processes. Researchers in the lab are involved in a large number of ongoing projects on a wide range of topics, providing the opportunity to incorporate diverse research areas into outreach material.

2 Methods

2.1 Teaching Module

The goal of the teaching module we developed is to introduce students to the theory and techniques used in geochronology (Fig. 1). The module is based around U-Pb dating and includes theoretical exercises on radioactive decay and isotopic measurements and practical exercises on mineral separation. The combined exercises expose the

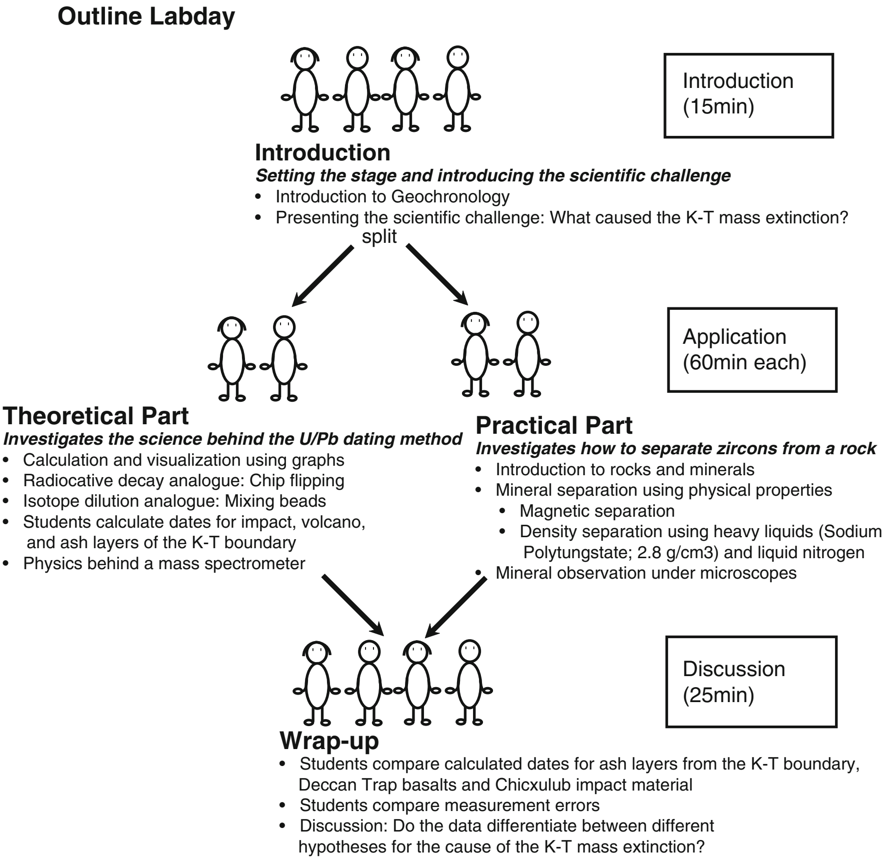

Fig. 1 Overview and outline of the Lab Day to demonstrate the different teaching actions (This figure was produced using the program Adobe Illustrator)

students to all of the steps in U-Pb dating, from sample collection to data interpretation. To provide a context for the exercises, we structured the module around the overarching theme of determining "What killed the dinosaurs?" However, the module is flexible and can be adjusted to a range of different topics (e.g., early Earth, climate change).

The experience starts with a short lecture that introduces to the idea of geologic time, the importance of geochronology for understanding Earth processes, and some background on the Cretaceous-Tertiary (K-T) boundary. The students are then split into two groups, to work on theoretical and practical exercises.

(A) *Practical Exercises*
In the practical section, students are introduced to the difference between rocks and minerals and examples of both. This exercise models the steps from collecting a rock sample to separating zircon, a key mineral in U-Pb geochronology.

Fig. 2 Students working with sodium polytungstate (yellow "heavy liquid") to separate the minerals by density. Liquid nitrogen (foreground) is used to freeze the heavy minerals in the bottom of the vial while the light minerals are poured out

Students go through a series of experiments to show how different minerals can be separated based on their physical properties. The techniques introduced in this section are regularly used in geochronology laboratories around the world. The mineral separation experiments include:

- Magnetic separation: Students are given a crushed rock sample and use strong magnets to separate magnetic and nonmagnetic minerals.
- Density separations: Students take the nonmagnetic minerals from the previous experiment and separate them based on density. The students place the nonmagnetic minerals in vials of sodium polytungstate (Fig. 2), a heavy liquid with a density of ~2.8 g/cm^3. The vials are put in a centrifuge and the dense minerals sink to the bottom, while the lighter minerals float on top. The students then freeze the bottom of the vials in liquid nitrogen and dump the less dense minerals into filter paper. After the dense minerals defrost, they are dumped into a separate filter paper.
- Mineral observation: Finally, students observe pre-prepared heavy mineral separates under an optical microscope with a large working distance (Fig. 3). The students discuss how different minerals look under the microscope and are given the opportunity to manipulate individual grains using fine-tipped tweezers.

Fig. 3 Students working with microscopes to pick zircons in the practical part

(B) *Theoretical Exercises*

In the theoretical section, students are introduced to isotopes, radioactive decay, and how isotope ratios and half-lives can be used to determine the age of a mineral. This content is described in detail in the online lesson plan for teachers. The students complete three exercises:

- Exercise 1: Students use worksheets to track the relative abundance of parent and daughter isotopes during radioactive decay. They plot changes in parent, daughter, and parent/daughter ratio through time. This exercise introduces radioactive decay, half-lives, and the use of parent/daughter ratios for determining the age of a mineral.
- Exercise 2: Students model radioactive decay by flipping chips with periodic table abbreviations for uranium on one side and lead on the other (Fig. 4). The students then determine the ratio of chips representing uranium to those that represent lead and use the ratio to calculate an age. This reinforces the concept that the parent/daughter ratio can be used to calculate an age, regardless of the initial number of parent isotopes.
- Exercise 3: Students use plastic beads to model isotopic ratio measurement made by isotope dilution. In the isotope dilution method, a known amount of a tracer isotope is added to a sample and used to determine the amount of

Fig. 4 Student working with the two-sided chips (part of the teacher material kit) to model radioactive decay in the theoretical part

Fig. 5 Students working with the beads (part of the teacher material kit) to determine ratios. The *colored beads* represent atoms and were mixed in a bowl beforehand for the isotope dilution exercise of the theoretical part (Color figure online)

each isotope in the sample. The students are given a large tub full of clear beads, which represent ^{206}Pb atoms. To determine the total number of ^{206}Pb atoms, without counting every bead in the tub, a known number of ^{205}Pb atoms (red beads) are added to the tub and mixed in. The students then count the ratio of $^{206}Pb/^{205}Pb$ beads in small subsets of beads (Fig. 5) and then use the counted ratio and the known number of ^{205}Pb beads to calculate the total number of ^{206}Pb beads in the original tub. This provides a very good model for how isotope ratios are actually measured, and the data the students generate is used to introduce the concept of measurement uncertainties and to calculate the age of different events related to the K-T boundary.

After both units conclude, the students are reassembled to summarize and reinforce the information presented. Students pool their results from the first unit, where they determined the age of the extinction and two possible extinction mechanisms. The "dated" samples include ash beds from above and below the dinosaur extinction event within a sedimentary section and material related to both a large volume volcanic eruption in India (Deccan Traps) and a major impact structure in Mexico (Chicxulub crater), which have both been proposed as possible causes of the extinction. After a discussion about cause-and-effect relationships and geochronological data, students are then guided through interpretation of their data.

2.2 Teaching Settings

We named the educational module Lab Day because the main goal of the workshop was a laboratory, hands-on teaching style. We adapted and taught the module in three different settings over the course of 2 years: (A) "Lab Days" at the MIT museum, where students were brought to the museum as part of a daylong field trip; (B) "Lab Day on the road," where researchers brought equipment into a high school classroom; and (C) "Lab Day teacher workshop," where researchers met with teachers, demonstrated the module, and answered questions to help them incorporate it into their lesson plans.

(A) *Lab Days*

The first Lab Day event was held at the MIT museum in April 2008 as part of the internationally recognized Cambridge Science Festival, a weeklong event designed to promote interaction between the science, technology, engineering, and math communities in Cambridge, MA, and the general public. We advertised within schools in the greater Boston area for a geology-related school field trip. Three 12th grade classes (35 students) from different high schools were invited to join us for a 4-h workshop, followed by a video-streaming webcast, called "Q and A with the scientists." The program was successful and received positive feedback from students and teachers. Based on the feedback and our own observations, we adapted the lessons and expanded the program for the Cambridge Science Festival in April 2009. This event was again held at the MIT museum and included 9th and 10th graders (58 students) from two different schools. This time, as a prearrangement, students prepared short essays about their conception of geochronology. The outstanding results and the strong interest for outreach in geosciences led us to organize a third Lab Day later that year. In December 2009, we adapted the program again, with 9th grade students from one school (214 students) visiting the MIT museum over 3 days. The Lab Day program was shortened to facilitate the large number of students. During the event, the instructors were largely the same five scientists that led the other workshops. This time, to measure and compare students' understanding and to evaluate long-term results of our methods, pre-test were completed 1 week before the visit, and two post-tests were taken, 1 week and then 4 months after the visit. Detailed evaluation will be described below. To ensure a convenient campaign and participation of schools regardless their financial background, bus transportation and bagged lunches were provided for visiting students and teachers for all of the workshops.

(B) *Lab Day on the Road*
In May 2009, we modified the Lab Day exercises so that they could be transported to a classroom. In the first test of the new program, five scientists visited an all-girls school in Massachusetts to teach a class of 10th grade students. The scientists ran a 4-h workshop in the classroom using laboratory equipment brought to the school. Since the original design of the module utilized equipment available in the MIT museum, some presentations needed to be adjusted and replaced by posters and other activities. Written feedback from the students was collected 1 week after the visit.

(C) *Teacher Workshop*
After the initial Lab Days, we saw the need to include teachers in the program and to obtain more detailed feedback from educators, as well as to reach out to schools to advertise our program. In July 2009, as part of a teacher workshop at a local university, we introduced 27 science teachers to our curriculum. Written feedback from the teachers was obtained directly after the course and is not further addressed here.

2.3 Online Module

Based on our experiences in the Lab Day workshops, we produced a detailed lesson plan (31 pages) for the theoretical unit, which covers the principles of radioactive decay and isotopic dating. The lesson plan has been http://www.earth-time.org/Lesson_Plan.pdf from the EARTHTIME webpage since May 2009, and a teacher material kit is available by request in the USA. The kit and material provide a ready-to-use lesson plan, which was one of the most common requests in the teacher workshop. The online article describes teaching suggestions, teacher background knowledge, and learning goals and their correlation to national science concepts (a standard for unifying concepts and processes, given by the National Committee on Science Education). It provides worksheets for the exercises and a Microsoft Excel spreadsheet containing the necessary calculations. The material kit consists of three bags with 500 colored beads each (red, white, and blue), a bag with 100 two-sided chips (U/Pb on either side), a cup to take out samples, and a mixing bowl; a video demonstration of how to use the kit is available online. More than 50 kits have been requested and sent out to different schools in the USA so far.

3 Evaluation/Data Analysis

To evaluate the effectiveness of the module and use the participants as a resource for criticism, we solicited written feedback after each Lab Day presentation and used these comments to continually improve the exercises. To obtain more detailed statistical data for the December 2009 "Lab Day," we conducted a pre- and two different post-tests to compare short- and long-term learning outcomes. The pre-test was completed the week before the visit to the MIT museum, the first post-test was carried out 1 week after the visit, and the second post-test was done 4 months later. The middle and high school teachers gave each of the tests in their class room setting, and we had no influence on their implementation. However, we asked teachers not to help students with the questions. We also made it apparent that students would not be graded for their answers and that the survey would be solely for assessment of our teaching methods and would be treated anonymously. Students were given sufficient time to complete the questionnaires, which usually took less than 7–10 min. In the following sections, we focus on the results from the December 2009 Lab Days, because the pre- and post-tests from these workshops provide the best quantitative measure of the success of the teaching modules and Lab Day model.

The pre-test questionnaires consisted of the following four quantitative multiple-choice questions to test general content knowledge:

1. How old do you think the Earth is?
   (a) 1.23 million years
   (b) 2.34 thousand years
   (c) 3.45 trillion years
   (d) 4.56 billion years
   (e) 5.67 million years
2. What is a half-life?
   (a) The time when one half of a rock is eroded
   (b) The time when one half of the earth was formed
   (c) The time when one half of radioactive atoms decayed
   (d) The time when magma cooled enough to form a mineral structure
   (e) The time when half of the molecules have formed covalent bonds
3. What minerals are often used to date older rocks?
   (a) Quartz
   (b) Ruby (Corundum)
   (c) Zircon
   (d) Olivine
   (e) Obsidian
4. What is one dating method for determining the age of a really old rock sample?
   (a) Uranium-lead dating
   (b) Radiocarbon dating
   (c) Potassium-argon dating
   (d) Uranium-thorium dating
   (e) Tree-ring counting

We selected these questions because they provided the best quantitative measure of learning in our initial questionnaires from earlier “Lab Days.” The first two questions deal with topics that might have been covered at some point in the school curriculum, while the last two questions are more specific to our module. In hindsight, we realized that question four was poorly worded, although it still likely serves as a useful monitor of the effectiveness of the modules (discussed in the study limitations). Both post-tests contained the same quantitative questions as the pre-test and two additional qualitative questions:

5. Name three things you learned at your Lab Day. (Three open answers possible)
6. What exercise was the most interesting and fun part of your Lab Day experience? (One open answer possible)

Parents/guardians were informed of the project and testing beforehand and signed written consent forms. Although students were granted anonymity, some of them did use their full names and others used initials or first names only. Names/initials were only used to match the pre- and post-tests. There was no distinction made between male and female students. Of the visiting 214 students, all three tests (pre-test and two post-tests) could be matched for 144 individuals ($n = 144$). This is due to some students not being present at one of the three testing dates in school or being unable to correlate pre- and post-tests due to missing names/initials. The long-term post-test from one participating group could not be obtained and was omitted from further consideration.

All tests results were normally distributed. To measure the difference between pre- and post-test, we ran two paired *t*-tests for the quantitative set of multiple-choice questions as a whole, one for the pre- and post-test and another one for the pre- and the long-term post-tests. We also investigated the change in each of the four quantitative questions and ran the paired t-tests for each question, examining the change from pre- to post-test, from pre- to long-term post-test, and also between the two post-tests. To quantify the effectiveness, we used the standard *t*-test *p* value (probability value): a small number indicates the module is effective while a large p value would indicate that the taught module seem to be ineffective. We defined the means of statistical significant difference as follows: p value <0.05 validates statistical relevance, marked with one *; p value <0.01 shows a strong relevance (**); p value <0.001 states high significance (***).

4 Results

4.1 Quantitative Questions

The results of the two paired *t*-tests examining the overall performance are shown in Fig. 6. Participants achieved significantly different performances in the overall pre- and post-phase and in the pre- and long-term post-phase, with a p value <0.01 in both cases. The increase in correct answers from the pre- to the first post-test demonstrated the effectiveness of our module: 67 % of the questions in the pre-test were answered correctly, while in the first post-test, 85 % were answered accurately. The long-term post-test shows a slight decrease in correct answers to 83 %, but the change is not

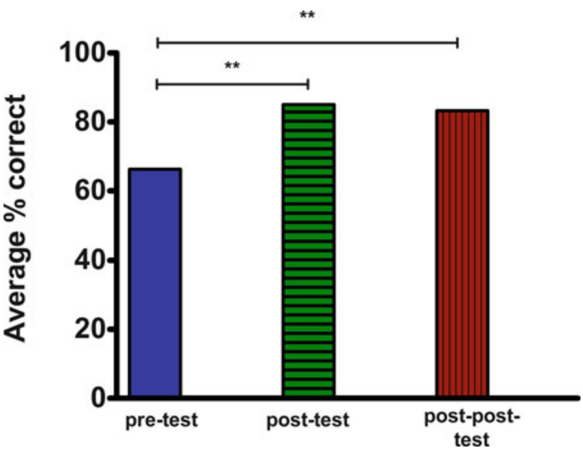

Fig. 6 Averaged results of the four quantitative questions for each test phase (percentage of correct answers). Statistical significance was measured by running two paired *t*-tests. $n = 144$, p value <0.01 for both *t*-tests. *Stars* indicate statistical significance as described in the Results section. Pre-test, 1 week before the visit: 67 % correct answers. Post-test, 1 week after the visit: 85 % correct answers. Post-post, 4 months after the visit: 83 % correct answers (This figure was produced using the program Graphpad)

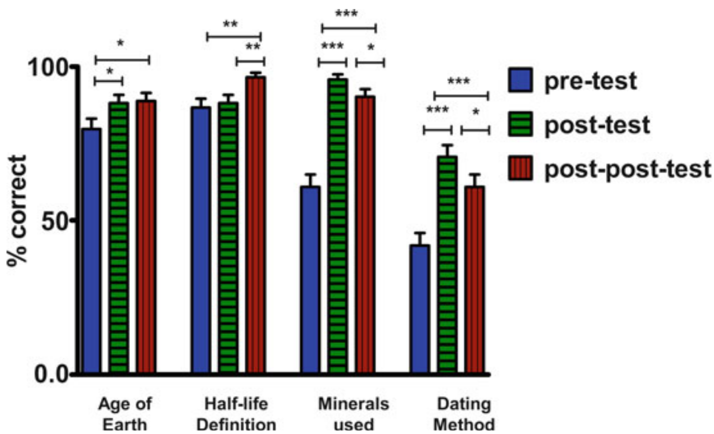

Fig. 7 Detailed chart with the four questions that were used for the paired *t*-tests for each test phase in Fig. 1. $n = 144$. *Stars* indicate statistical significance, as described earlier; *no star* indicates there is no statistical change between test phases (p value >0.05) (This figure was produced using the program Graphpad)

statistically significant (p value > 0.05). The decrease in correct responses was largely related to questions 3 and 4, visible in Fig. 7 and described below.

Figure 7 illustrates responses for the four questions used for the paired t-tests. Most students already answered question one (How old do you think the Earth is?) correctly in the pre-test (79 %). However, there was a statistically significant improvement for the post-test (87 %, p value = 0.02) and from the pre- to the long-term post-tests (88 %; p value =0.02). For the second question (What is a half-life?), the students did well in the pre-test (86 % correct answers), and there is no significant increase for the post-test (87 %; p value = 0.6). Interestingly, the half-life definition advanced further 4 months later for the long-term post-test (96 %) and thus shows a significant increase for both t-tests (p value =0.0015 from pre- to long-term post-test and $p = 0.004$ for post- to long-term post-test). This may be due to later reinforcement in students' secondary school curriculum. Overall, correct answers in the post- and long-term post-tests improved for these two questions.

For the third and fourth questions ("Which minerals are used to date older rocks?" and "What is one method used to date older rocks?"), there was very significant improvement in both post-tests relative to the pre-test. For the third question, 60 % answered the question correctly in the pre-test, whereas 95 % (p value <0.0001) answered it correctly in the post-test and 89 % (p value <0.0001) answered it correctly in the long-term post-test. For the fourth question, 40 % answered the question correctly in the pre-test, whereas 70 % (p value <0.0001) answered it correctly in the post-test and 60 % (p value =0.002) answered in correctly in the long-term post-test. The improvement can be attributed to our curriculum, since these topics were not covered in other classes.

Small score decreases for the long-term post-tests compared to the immediate post-tests are not significant for the overall performance (Fig. 6), but are significant when the questions are compared separately. The long-term retention of the knowledge was not as strong for the third and fourth questions (p value = 0.045 and 0.023, respectively). This may reflect the fact that the first two questions were likely reinforced in other classes. However, despite the slight decrease in correct answers between the two post-tests, the last two questions still exhibited large improvements from the pre-test to both the post-test and long-term post-test, demonstrating the positive impact of our program and its long-term benefit. Students may have later forgotten what they learned in the module and reverted back to familiar answers or preconceptions. For the third question, students correctly answered "zircon" a week after the visit, while 4 months later a significant percentage of students changed their answer to quartz, a better known mineral. For the fourth question, although most of the students correctly answered that the U-Pb system is used for dating very old rocks in the first post-test, some students changed their answer to "radiocarbon dating" 4 months later. Radiocarbon dating is commonly referenced in public and in the media, and it is sometimes used as a general term for measuring arbitrarily old dates. The distinction between different isotopic dating methods and which samples can be dated with which method is rarely made. This might explain why students ticked the well-known name radiocarbon instead of the lesser-known U-Pb dating method.

4.2 Qualitative Questions

Describing all the results of the qualitative questions of the pre- and post-tests is beyond the scope of this chapter. However, in this section we summarize the main outcomes and implications. All answers to the two qualitative questions were collected and then, if possible, categorized and summarized by topic.

Question #5 (*Name three things you learned at your Lab Day*)

For the first qualitative question, students could name three things they learned. Answers were categorized by similar answers or specific terms. Most students named zircons in some way. This would include the most stated answer “separate zircons from rock” as well as physical properties of zircons (“zircons are nonmagnetic” or “zircons are heavier/denser than other minerals”). Some even answered “zircons can be used to date rocks.” The second most common category consisted of answers that mentioned the framework theme of our exercise, the K/T boundary and mass extinction. Both answers were still well represented in the long-term post-test 4 months later. Answers containing something about mass spectrometers and isotopic ratios were prevalent in the week after the experiment, but were marginal 4 months later. These again are topics that not usually covered in school, and even though they may have made an impression, without further reinforcement, they are not the first terms that come to students’ minds when reflecting on the experience. On the other hand, categories that included radioactivity and half-lives were not the most common in the post-test, but gained more attention after 4 months – possibly because they had been covered in science classes and teachers could refer to our experiment. This suggests that out-of-school trips are an effective way to introduce a new topic, which can then be further discussed in the classroom to reinforce understanding and establish a long-term effect.

Question #6 (*What exercise was the most interesting and fun part of your Lab Day experience*?)

The second qualitative question was easier to categorize. Students were asked to name the most fun and interesting part of their experience, and we divided the responses based on whether the experience they listed was part of the practical or theoretical section. The practical and theoretical parts were then further subdivided into the different exercises in each section that were most popular. The practical part was clearly favored by students: 84 % (88 % in the long-term post-test) of the students named one of the hands-on laboratory elements as their favorite part in the two post-tests, while 9 % (11 % in the long-term post-test) named fractions of the theoretical part as more fun. The most favored practical exercise was using the liquid nitrogen to freeze heavy minerals in the sodium polytungstate, and the most favored theoretical exercise was the isotope dilution bead problem. These responses support our hands-on teaching approach.

4.3 General Written Feedback from Teachers and Students

Teachers noted that there is a need for educational modules to be taught in different settings as well as with different applications. Our approach with the geochronological relevance of radioactivity was praised by geology, chemistry, and physics teachers as a unique approach. Even though the laboratory modules cannot be carried out in school due to lack of equipment, our material kit was stated to be an excellent representation of radioactive decay. Some teachers made it clear that they were trying to avoid the topic of radioactive decay but now feel more confident in teaching it after completing the teacher workshop and being able to use the bead model.

Notable student quotes included the following: “cool doing something new and different,” “didn’t know rocks could be so cool,” “interesting that mathematics can actually be used for exciting topics,” and “nice to be at MIT and work with real scientists and see what they do.” The students valued being included in something that felt like how science is done in a lab, and they were fascinated to see the dedication to our jobs/studies and that scientists are excited about what they are doing. They were amazed to hear how many different places geologists can visit and conduct research in and what a broad range of topics are included in geology.

4.4 Study Limitations

All our results were confirmed by testing day-to-day variation in the responses (not further explained here), so we are confident in our positive learning outcomes in general. However, testing methods always have drawbacks, and we would like to illustrate possible factors: for question four, we did not clearly quantify “really old.” The uranium-thorium and radiocarbon techniques can be used to date samples that are thousands of years old and so could be considered correct answers. In addition, potassium-argon dating can be used to date geologic events over the same time range as uranium-lead dating and is also an appropriate answer. Because the Lab Day teaching module stressed the uranium-lead technique, and other techniques such as potassium-argon are likely not well known to the students, we do feel that the statistical variations in the number of “correct” answers likely reflect the amount of material the students retained from the Lab Day exercises, despite the poor wording of the question. We could not supervise the testing in class, and even though we asked students to give their true opinion and told them they would not be graded, we can never check if they copied ideas from one another. Although we asked teachers not to mention specific terms, it is possible that a teacher or a student made a well-intentioned suggestion (e.g., “remember the Lab Day where we did…”) that could have altered the data. Also, not all long-term post-tests came back, and in general, the feedback from teachers and students still seems to be limited when written. An oral feedback discussion would be ideal but was not feasible due to time constraints. Also, another third longer-term post-test (e.g., 8 or more months after teaching the module) would be useful for assessing the long-term benefit of the Lab Day model. In general, the very positive test results might not be completely representative for a typical 14-year-old high school student. One of the teachers we contacted for the project was already known to be interested in the subject and therefore might have covered parts of the topic in class beforehand. Also, teachers would not want students to look too uninformed when visiting a research university, so the topic might have been covered briefly beforehand. Finally, nonresponses may have selectively biased the later tests toward students who were confident of the correct answers.

5 Outcome of the Project and Conclusions

To quantitatively assess learning outcomes and the long-term impact of the outreach program, we used pre- and post-testing. The data show that many students learned and retained knowledge of U-Pb dating from the practical and theoretical exercises. We used the additional input to adapt the lesson plan and provide more detailed instructions for science teachers. The assessment results demonstrate that complex concepts are retained over the short and long term. However, topics that have not yet been covered in school and are not repeated after the visit are not retained as well over longer timescales. We suggest reinforcing difficult concepts in multiple settings (i.e., out of school and in school) and that a wrap-up after school trips might have a stronger impact on learning. In general, we propose that conducting outreach with scientists is a highly successful way of engaging students and should be a part of every research facility to foster curiosity and appreciation of science.

From this study we are able to conclude that teachers appreciated the hands-on activities that placed complex subjects in a wider context and ready-to-use lesson plans, especially in interdisciplinary subjects such as the geosciences that are not usually part of the school curricula. Teachers also welcomed the chance to further explore unfamiliar material during workshops taught by research scientists. Students generally enjoyed the hands-on laboratory experiments and the opportunity to encounter and scientifically evaluate an ongoing research project with professional scientists.

Our results also show that the EARTHTIME outreach initiative and its efforts to bring cutting-edge scientific research to schools and the public are effective at fostering scientific literacy at an early age. We created an educational module to provide students with hands-on exercises in geoscience, which covered material from geology, mathematics, physics, and biology. Continuous feedback from students and teachers helped adapt the module to their needs.

5.1 Perspective

The ready-to-use lesson plan for teachers with clear instructions is downloadable from the EARTHTIME web page (www.earth-time.org). Material kits accompanying the lesson plans have been sent out to more than 50 schools US-wide, and the module has been presented at three international conferences. In Vienna, Austria, the German translation of the lesson plan has been adapted for younger students and is in frequent use with the material kit, e.g., at the Children's University.

Overview

Background and Motivation

– An educational module about uranium/lead dating and geologic time was developed as part of the EARTHTIME outreach initiative. Our goal was to combine theoretical exercises and hands-on experiments that expose high school students (age 14+) to real research methods and problems. The module builds on multiple existing school subjects, including physics, chemistry, and biology. The ambition was to test whether complex scientific topics can be successfully taught in high schools, using hands-on activities to model multifaceted processes.
– We have provided a convenient lesson plan that covers topics of general interest and incorporates cutting-edge research, because science teachers often do not have the chance to be up-to-date on current research.

Innovations and Findings

– Students appreciated exploring a new topic in a different environment, and students and teachers both enjoyed interactions with "real scientists about a real scientific topic."
– Although the curriculum was demanding, we observed a statistically significant increase in short- and long-term learning outcomes for the program.
– Students also made connections between different branches of science and observed that mathematics and physics could be applied to solve problems in earth science.

Implications for Wider Practice

– Our data suggests that high school students benefit from visiting earth science research facilities. We suggest that even complex topics taught by scientists using hands-on activities can facilitate learning. If teachers have accurate teaching materials and training, they can work together with students to teach sophisticated scientific concepts. For a research institution, the development of such a module requires commitment in administration.
– We propose that topics that seem to contend with general preconceptions need to be addressed further, repeatedly, and with different teaching methods to gain a durable effect. Also, to accomplish an understanding and knowledge gain for all students with different learning skills, it might build a longer-lasting impact if challenging topics are covered in lessons in school as well as field-trip experiments with different applications.
– With the teaching module and kit, we would like to give teachers the opportunity to address different topics without a field trip, even if these can only work as inspirational samples since teachers already have to cover a substantial amount of science topics in classes.

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Little Meteorological Workshop: An Extracurricular School Activity for Pupils

Kornelija Špoler Čanić and Dubravka Rasol

1 Introduction

Science has become an essential part of human heritage (Popli 1999). The knowledge and outlook of science can be useful in virtually all parts of everyday life. Therefore, communicating science is crucial.

Croatia has long tradition of communicating and popularising science (Croatian Natural History Society 2010), but there is still a lack of regularly occurring activities. Wilson (2008) observed that in some cases, television weathercasters are the only source of scientific information that some Americans encounter on a regular basis, and the situation in Croatia is very similar. An example of good practice is the Science Festival (SF), the largest science popularisation event in Croatia (www.festivalznanosti.hr). The first SF, opened at the British Council's initiative, occurred in 2003. Since then, SFs have been organised in more Croatian cities every year. Typically, SFs are 1 week in length, and they usually are scheduled to include Earth Day (April 22). Furthermore, over the past 10 years, open days held by some scientific institutions have become common practice, and the Researchers' Night event (http://ec.europa.eu/research/researchersnight) was first held in Croatia in 2010.

At almost all of those events, meteorologists participated via lectures and workshops; however, with regard to the public's routine exposure to meteorology, forecasters are the only communicators and educators. Sharing knowledge of meteorology is very important, especially for increasing awareness about the

K. Špoler Čanić (✉)
Department of Management and Information,
Meteorological and Hydrological Service of Croatia, Zagreb, Croatia
e-mail: spoler@cirus.dhz.hr

D. Rasol
Department of Weather and Climate Monitoring,
Meteorological and Hydrological Service of Croatia, Zagreb, Croatia

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contemporary problems associated with climate change and environmental pollution. Phenomena such as global warming, sea level rise, water pollution and air pollution significantly affect the public's quality of life. Therefore, more than just a weather forecast must be communicated. In almost all areas, knowledge of meteorology and climatology is one of the main prerequisites both for sustainable community development and for addressing today's various environmental challenges.

This chapter presents teaching techniques and ideas that we have found to be effective in sharing knowledge of meteorology. These techniques were developed during implementation of the Little Meteorological Workshop (LMW).

2 Implementation of the Little Meteorological Workshop in Schools

The LMW is an educational project designed to popularise meteorology. The project started in 2007, when it was first executed at the SF in Zagreb. The audience at the SF ranges from kindergarten-aged children to adults, but the majority of the group consists of primary- and high-school pupils. In science-related school activities, pupils are often just passive listeners and observers. If teachers conduct experiments during these activities, they usually use complicated equipment and terminology that often leads the majority of pupils to conclude that science and research are very complicated. In the LMW, we tried to avoid that approach. For the SF, we prepared experiments that can be performed without any special skill or expensive equipment. The experimental equipment used in the LMW consists of household objects, waste materials and some school supplies. A simple instruction sheet for each experiment was prepared, and the participants of the LMW could perform the experiments largely unassisted. We participated in the LMW only as moderators and assisted when needed.

We have continued to participate in the Zagreb SFs, but we wanted to include more children in the project, especially those without the ability to attend SFs. For that reason, we started a new phase of the project in which the LMW is presented as an extracurricular school activity. This part of the project was termed the Little Meteorological Workshop in Schools (LMWS). The content of the LMWS is adjusted for children in the 4th grade (approximately 10 years old) and their teachers. That age level was chosen because pupils typically learn some basic meteorological terms during the 4th grade. In addition, the majority of the children at that age still feel free enough to ask questions and to show their curiosity.

The duration of a LMWS is 45 min. All children in a class attend the workshop (i.e. there is not a particular selection of children who attend the workshop). The number of participants varies from 8 to 28, and the class's teachers are also present at the workshop. The lecture is divided into three main parts: the introduction, the practical work and the completion of a questionnaire.

The introduction section includes brainstorming about meteorology. The purpose of the introduction is to raise the children's awareness about their knowledge of meteorology through an interactive dialogue. The introduction also serves to raise their interest in the next section: the practical part of the workshop.

Fig. 1 "One for all and all for tornado"

In the practical part of the workshop, three experiments are performed. The first and the third experiment are conducted by children in groups, and the second experiment is conducted by the whole class together with one assistant/performer. The first experiment is always the "tornado" (Fig. 1). In this experiment, children connect two plastic bottles with waterproof adhesive tape. One third of one bottle is filled with water. Once the bottles are connected, the children rotate them and make a whirlpool that reminds them of a tornado. The tornado is a very attractive experiment because it is simple, very dynamic and demonstrative. This is the experiment that children like the most (see the information regarding the participants' evaluations). They enjoy rotating the bottles to see how their tornado can be fast, slow, thin or thick. Playing with the tornadoes (i.e. water) is fun, so children are always happy and relaxed after the first experiment, and their mood helps to make the remainder of the workshop much better. For this reason, the tornado experiment is always the first one performed in a class. We assist children in making the experimental apparatus, and we encourage them to independently note the basic characteristics of a tornado. Additionally, we give them some interesting information about tornadoes, including (1) the geographical regions where tornadoes appear most frequently, (2) an explanation of the similarities between a tornado and a waterspout and (3) some tornado-related anecdotes. After each child in a class has a turn to spin a tornado, the class is ready for the second, central experiment of the workshop.

The central experiment is performed by one assistant together with all of the class's children. The central experiment is one of the following: "thermometer", "fog/cloud", "barometer", "air pressure", "carbon dioxide" or "acid rain" (Fig. 2).

Fig. 2 Testing the acidity of rainwater with an indicator made from red cabbage leaves

If we present LMWS to more than one class in the same school, then we do not repeat the same central experiment between workshops. We presume that the teachers of different classes will discuss the content of the workshop. By offering different content in each presentation, the teachers can share their different experiences and knowledge, thereby obtaining maximum benefit from the workshop. It is important to emphasise to the teachers that different experiments were performed and to encourage them to share their experiences with each other.

During the central experiment, an assistant leads a conversation with the children, who help her or him to conduct the experiment. When the second experiment is finished, the children are again divided into groups, and the class is ready for the third (and final) experiment.

The third experiment is either "wind vane" (Fig. 3) or "anemometer". The role of the assistant during this experiment is the same as in the first experiment. When the experimental part ends, the last 5 min of the workshop are reserved for completion of the questionnaire.

To lead a class workshop as it has been described, it is necessary that some preconditions are fulfilled:

– There must be enough people (i.e. members of the LMWS team) that are competent and willing to perform the workshop in a class.
– The content and appropriate methodology for the workshop must be formulated.
– Some didactic material for the workshop must be prepared.
– The materials and tools for performing the workshop must be gathered.
– The school's manager must have interest in (and grant permission for) hosting the workshop.

Fig. 3 Testing a wind vane

– Teachers must be informed in advance regarding preparation of their class for the workshop.
– There must be good coordination between team members who are present at the workshop.

The LMW team consists of meteorologists from the Meteorological and Hydrological Service of Croatia (MHSC), graduate students of meteorology and one high-school physics teacher. At the time of this writing, the LMW team has nine members. The optimal number of team members is four, and the minimum number is three. These numbers permit a workshop to be properly performed with a class of approximately 25 pupils. It is important to note that all of the team members, in addition to possessing their meteorological background, should have a pronounced ability to explain facts in a simple way.

The core of the workshop is experiments. To select the experiments, we followed the same principles as those used during the SFs: the experiments should be simple and illustrative, and the materials and tools used in the experiments should mainly be household objects and waste materials.

We also prepared didactic materials (i.e. instruction sheets) for each experiment. The general form of the instruction sheets consisted of a title in the form "What is …?", a definition of the meteorological phenomena or instrument that was the topic of an experiment, a list of materials and tools for performing the experiment, a set of instructions regarding to conduct the experiment, a short explanation of what one could observe during the experiment (this part is intentionally placed on the back side of the paper), a description of interesting facts about meteorological phenomena or the experimental instrument and a list of useful links to websites (in Croatian and English) where children and teachers can find more information about experiments and meteorology in general. The instruction sheets also include our mailing address, and the children and teachers are encouraged to pose any future questions to us at this address. We believe that after the LMWS, children will realise how they can perform their own research projects with the instruments they have learned to make. We encourage them to construct a little meteorological station and to try monitoring the weather conditions from day to day. Those activities should improve their understanding of how a research project is conducted.

The LMWS is free for its users (i.e. pupils and teachers). The support of the MHSC, the Croatian Meteorological Society (CMS) and the Croatian Interdisciplinary Society (CIS) was crucial for obtaining funds for the LMWS that assured the availability of materials and tools for its performance.

Funding for the LMWS is limited, so we needed to be selective about the schools where the LMWS should be performed. In all of the selected schools, there is a lack of extracurricular school activities because the schools either are overloaded or are too far from activity providers.

When funding was assured and all of the required materials were prepared, the next step was to offer the workshop to the chosen schools. We contacted a school's manager, and if we obtained permission, then the date for performing the workshop was arranged. In most cases, the reaction from school managers was positive; permission was not granted in only one case.

Next, the teachers were contacted 1 or 2 days before the workshop, and we explained to them how to prepare children for the workshop. The teachers were asked to arrange groups of children and to stress that they should work as teams (but without competition among them). Unfortunately, Croatian pupils are not exposed enough to group work, and we have noticed that some pupils do not know how to work together with others, even though they perform well individually. Having the children work together is a great way to teach them about teamwork; consequently, group work is a very important aspect of the LMWS. Teachers were also instructed to tell children that the workshop leaders are not teachers, meaning that workshop leaders would not assign grades to a student's performance. If they believe that they will be graded on their performance, pupils often feel stressed and nervous, and their questions and answers are not spontaneous. It was also important to mention to the teachers that pupils are encouraged to pose questions because children sometimes are reticent in front of adults and should therefore receive extra encouragement to say what they think.

This preparation was quite important because when the teachers did not get the instructions before the workshop, we unnecessarily lost time. Most of the time was lost while forming the groups of pupils and while reorganising tables. Additionally, without proper preparation, the class's atmosphere at the beginning of the workshop was a bit tense. Creating a comfortable learning environment is crucial for having a successful workshop.

When we arrive in a class to start the workshop, good coordination between team members is necessary to maximise the children's and teacher's attention and minimise wasted time. One team member is the main moderator, which means that he leads the introduction part and gives some general instructions to children. When the introduction is finished, all team members start to distribute the instruction sheets, equipment and tools for the first experiment. It is important to note that these items are not distributed earlier so that the children are focused on the dialogue with the main moderator. When the whole class and one assistant are fully occupied with the second experiment, the other team members prepare working tables for the third experiment. In this way, the children have everything they need for the third experiment when they return to their groups after the second experiment.

3 Evaluation Methods and Results

To obtain objective feedback on the workshop, we constructed a questionnaire. The questionnaire is anonymous to ensure that we receive honest answers from the participants.

The questions in the questionnaire are the following:

1. Did you like the LMWS?
2. Would you like to attend the LMWS again?
3. Will you try to perform the experiments on your own?
4. Please rate each of the experiments.
5. Please rate the instruction sheets.
6. Please rate each of the workshop leaders (this part of the questionnaire is not mandatory).
7. Please write your comments (this part of the questionnaire is not mandatory).

To make the questionnaire as simple and straightforward as possible to ensure that it is easy and fast to complete, three answers (“boring”, “not bad” and “interesting”) were offered for questions 1, 4, 5 and 6. Each of the answer options was illustrated with an appropriate smile symbol to make the questionnaire more entertaining for children. For questions 2 and 3, participants could choose the answers “yes” or “no”. Questions 4 and 6 were followed by the list of the experiments performed and the workshop leaders for that particular class, respectively.

The first five questions comprise the main part of the questionnaire. Question 6 is not obligatory because not all workshop leaders have equally important tasks during a workshop. The main moderator and the assistant of the second experiment communicate much more with all of the participants than the other team members, who only assist two or three teams of children. These secondary assistants interact with fewer than half of the children in a class. However, the answers to question 6 can provide some useful information about the workshop performers, especially the main moderator and the assistant of the second experiment.

Between October 2009 and June 2011, the LMWS was performed for 1,221 children from 31 schools. More than 90 % of children liked the LMWS and would like to attend the LMWS again. To determine if children would perform the experiments in their free time, question number 3 was posed in the questionnaire.

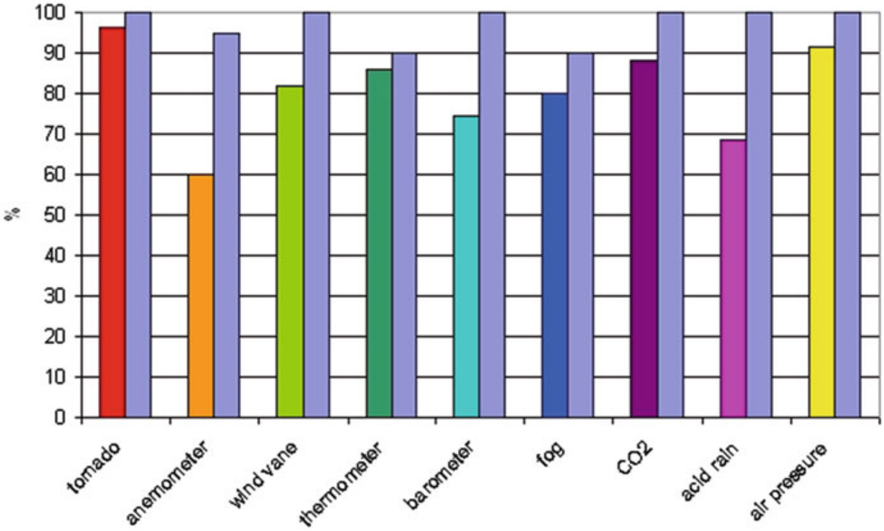

Fig. 4 Rating of the experiments. Student answers are to the *left* of each column pair, and teacher responses are on the *right*

Again, more than 90 % of the children responded positively. All experiments received good ratings (Fig. 4), and more than 60 % of the children found all of the experiments to be interesting. The most interesting experiments, according to the children's ratings, were the tornado and air pressure experiments. This result, however, should be regarded carefully because not all experiments were performed for all 1,221 children. Nevertheless, the results are comparable because each experiment was performed for a sufficient number of children. More than 80 % of the children found the instruction sheets to be interesting.

In addition to the pupils, teachers were participants of the workshop. So far, 46 teachers have participated in the workshop, and the teachers completed the same questionnaire as the pupils. In general, the teachers provided even higher ratings to the LMWS for all questions.

It is not mandatory to put comments in the questionnaire, but children and teachers often provided them. Some of the children's comments on the workshop included the following: "LMW is great", "It was great because I had a lot of fun, and when I am bored I will make these experiments again", "Everybody was cheerful while making the experiments, and they have chosen very nice experiments that occupied our attention", "LMW is great. I would like to attend it again. Performers are great!", "Meteorologists are interesting", "This workshop was great, and I would like you to come to our school again and that this workshop is an extracurricular school activity", and "Everything is very amusing and interesting, I think that you should go to a 'Super talent' TV show".

Teachers' comments included the following: "I hope that we will once again have an opportunity to attend your workshop. I am delighted!", "This was something new even for me; both my pupils and I enjoyed it", and "The workshops are very interesting and useful for pupils and teachers. I would like that there are more workshops like this one. Praise to the leaders".

4 Discussion

In the previous section, we explained the development of the LMW project from an activity in SFs to an extracurricular activity for pupils. The main advantages of the LMWS compared to the LMW at SF are the following:

- The ability to choose the audience's age, thus permitting better preparation of the lectures and instruction sheets
- The ability to choose of the duration of one workshop
- The ability to obtain objective feedback

Additionally, as described earlier, the main goal of this project is the popularisation of meteorology. Therefore, in addition to performing the LMWS, we try to do the following:

- Induce in children a positive attitude towards meteorology (and towards science in general), towards protection of the environment and towards the preservation of natural resources.
- Teach children how nature and humans are strongly connected and how natural resources are limited (and therefore should be preserved).
- Teach children about teamwork, communication, conflict resolution, critical thinking and the drawing of independent conclusions.
- Give children the opportunity to choose a quality activity that they can do in their free time.

In our opinion, the approach presented here for performing the LMWS is the most effective for popularisation of science among children. It is important to present science to children in an entertaining way, and its presentation should still reflect real science with no inaccuracies that are difficult to correct in the future. That is why all team members should be able to present science in a simple way that is understandable by children. Moreover, team members should love working with children and speaking about science.

Even though the presented evaluation results motivate us to spread our activity and to include more children in the project, there are some limitations to performing the LMWS. Two main limitations are manpower and funding. Despite our team's growth from two members to nine, the project still suffers from a lack of manpower. None of the members can work on the project as much as is actually needed. Because there is not enough funding for someone to work full time on the project, the only solution is to have more members on the team. Additionally, ensuring funding for the LMWS besides the support of the MHSC, CMS and the CIS is time consuming because applications for donations must be written. Moreover, finding new donors is important. All of these activities require substantial effort that does not always end in positive results, meaning that a great deal of enthusiasm and voluntary work is needed to run the LMWS.

The workshop concept presented here has one major advantage in that teachers are present at the workshops. Those teachers are also being educated on how to teach meteorology in an entertaining way. They can also transfer their new knowledge of meteorology to the future generations of pupils. Each of the teachers receives the instruction sheets for all of the experiments that are being performed in the LMWS, rather than only for the experiments performed in their class. Having all of the instruction sheets increases the possibility that the teachers will conduct additional experiments with the children from their class. If they encounter any problems with the experiments, teachers can contact the LMWS team members, who usually encourage the teachers to design their own workshop for their pupils. However, it is left to the teacher's choice whether they will implement this content in future lectures. In theory, teachers can prepare some extra materials for lessons, but in practice, they often do not have enough time for doing anything aside from the official school programme. Nevertheless, some teachers manage to conduct a few more of our experiments with their pupils. Whether the teacher conducts the experiments in their future lessons mostly depends on the teacher's character, interest in the improvement of the school programme and the teacher's interest in science. During the LMWS, we met different kinds of teachers. Some wanted to be a part of the workshop, but others were not interested in what we were doing. Some were happy that somebody else was doing their job for a while, whereas others felt offended that someone else was teaching. Fortunately, we have encountered more positive than negative examples.

At the present rate of workshop presentations, it would take many years to cover all of the primary schools in Croatia. In our opinion, the best way to give all teachers and pupils an opportunity to perform experiments is to publish a booklet of experiments. Therefore, we have prepared the material for a booklet that will be published in early 2012. The main content of the booklet was created from the instruction sheets corresponding to experiments prepared for the workshops. The booklet contains the following sections: preface, 20 experiments, basic clouds atlas, Beaufort wind force scale, useful links and references. Zoran Vakula, a popular Croatian forecaster, authored the preface. His cheerful approach to meteorology should increase children's, parents' and teacher's interest in the booklet. The booklet is richly illustrated, which should help readers in conducting the experiments. In addition, it should assure more interesting and entertaining content. To make experiments more attractive to the reader, the beginning of each experiment's section includes a humorous illustration related to the meteorological phenomena or instrument that is discussed.

The booklet's publisher is Školska knjiga, which has a long tradition and is well recognised among pupils because the majority of school books are published by the company. One advantage of publishing the booklet is the possibility that teachers can participate in workshops organised by Školska knjiga. In this way, we have an opportunity to present not only the booklet's content but also the methodology of the LMWS directly to teachers.

In addition to the LMWS and booklet, we are developing a website where the project is presented (www.malameteo.com). For now, the website comprises information about the project, some interesting data about the experiments, a photo gallery, some basic information about team members and contact information. In addition to the contact information, visitors to the website can also provide their comments related to the presented experiments. In the future, there will be more interactive content on the site, along with some English-language content.

Overview

Status Quo and/or Trends

- In Croatia, there is a lack of regular communication and popularisation of science, especially meteorology.
- For the majority of people in Croatia, weather forecasts are the only source of meteorological information; such limited exposure is insufficient to increase awareness about contemporary problems related to climate change and environmental pollution.
- Meteorologists participate in lectures and workshops at the events which aim to popularise and communicate science (e.g. the Science Festival (SF)).
- The Little Meteorological Workshop (LMW) is a project designed to popularise meteorology. It was started at the SF, but it has also been implemented as an extracurricular school activity.

Challenges to Overcome

- There are several preconditions necessary for the implementation of the LMW in schools: the selection of the target audience, the formulation of content and appropriate methodology for the workshop, the interest and permission of school managers for hosting a workshop, the assembly of enough people who have competency and willingness to perform a workshop and the gathering of materials and tools required for performing a workshop.

Recommendations for Good Practice

- The methodology used and evaluated at LMW in schools is, in our opinion, a good example for teachers to learn how to provide dynamic and educational lectures about science.
- A published booklet of experiments is one way to support science activities in classrooms.
- We encourage students and colleagues to perform similar activities because both groups learn new skills and acquire new knowledge. Therefore, pupils, teachers, experts and students performing a workshop will all benefit from these activities.

Acknowledgements First, we would like to thank our colleagues Krešimir Čanić and Kristian Horvath, who joined LMW team and gave us support in organising and leading the LMW in schools. We would also like to thank our young colleagues Ivana Tomašević and Nikola Vikić Topić, students of meteorology, for their active participation in the project. We would like to thank all of our donors, without whose support, the realisation of this project would be much harder. These donors are the Ministry of Science, Education and Sports; the Meteorological and Hydrological Service of Croatia; the Department of Geophysics – Faculty of Science, University of Zagreb; the Foundation of Academy of Science and Art; the City of Zagreb; the City of Rijeka; Microton – slušni aparati d.o.o.; and Zagrebački holding d.d.

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Grasping Deep Time with Scaled Space in Personal Environs

Bo Holm Jacobsen

1 Introduction

The concept of deep time has been a cornerstone of geology since the days of the renowned George Hutton.[1] In this chapter, deep time is taken more broadly as the deep past before written history, all the way back to the Big Bang, and the deep future from the time of our grandchildren and beyond the lifetime of our Sun.

Does it matter whether non-scientists understand deep time? Yes it does, not just in view of a general aspiration towards public scientific literacy. Present societal evolution and political decisions imply severe long-term effects on climate, biodiversity and critical resources. Thus, sustainable policymaking in democracies will require informed political debate which again will require a scientific understanding of deep past and deep future among ordinary citizens.

The purpose of this chapter is to present several examples of scaled geological time to help people understand the concept of deep time and how it projects into the future. Scaled time is not a new idea, as exemplified in numerous installations called time walks or geology paths. The present project differs from these examples in that the scaling of time is fixed, and the scale is defined so that 1 mm represents the life expectancy of a young person, i.e. 100 years. This choice obviously makes mental calculations easy and so helps the citizen gain ownership to this learning tool and hence to time. In the following, citizens will be referred to as pupils and students although also adults are very relevant learners.

[1] http://en.wikipedia.org/wiki/Deep_time

B.H. Jacobsen (✉)
Department of Geoscience, Aarhus University, Aarhus, Denmark
e-mail: bo@geo.au.dk

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Despite the vast proportions between durations of processes and between separations of events, we shall insist that there is only one timeline, containing individual life projects as well as galactic life cycles and what lies in between.

Clearly, the mapping of events in the history of man, life, Earth and known universe is a simple exercise at all teaching levels where these matters come up. For easy reference, let us first emphasise some simple conversions:

10 μm	= 1 year
1 mm	= 100 years
1 cm	= 1,000 years = 1 ky
1 m	= 100 ky
10 m	= 1,000 ky = 1 My
10 km	= 1,000 My = 1 Gy
137 km	= 13.7 Gy = time so far

The scale of past time is discussed in the following order with the fundamental unit of 1 mm. Numbers refer to chapter subsections:

1.1 The millimetre scale under a microscope encapsulates a student's personal history.
1.2 A credit card encloses all of human history.
1.3 The student's desk hosts the age of "humans like us".
1.4 Walking the classroom and the hall outside takes a student through the swarm of ice ages and human evolution in the Quaternary.
1.5 Outside the classroom and down a few blocks is in the Cenozoic – the age of mammals and the K–T boundary.
1.6 A one-hour walk traverses the age of footprints on land since the Paleozoic.
1.7 A day trip by bike takes students back to the beginning of Sun and the Earth.
1.8 A one-day excursion by car reaches the Big Bang.

The understanding of deep future is perhaps the most interesting challenge and the main motivation for this chapter. The next millennia as well as the geologically deep future, i.e. millions to billions of years, are discussed in Sect. 1.9.

1.1 The Millimetre Zoom on Personal Life Projects and Recent History

The individual life story is represented by an interval of 1 mm. Figure 1 shows a close-up of the millimetre ticks on a ruler. It is straightforward for the student to magnify even more using a simple microscope and add tick marks at the personal milestones between pre-school, school, high school, career, marriage and retirement, using a pointed needle.

A single millimetre, slightly shifted, also accommodates the time of globalising democracy, women's rights, pervasive technology and global wars.

1.2 The TimeCard: The Holocene and History

The first centimetre covers the growth of colonial globalisation, the Renaissance and the Late Middle Ages. The second centimetre takes us past the Vikings and the Arab expansion to the zenith of the Roman Empire. Within the few centimetres of a credit card (see Figs. 2 and 9), we may map out also the classical history of the first large cultures in the Middle East, India, China and America. To most people, this is what they consider as important and mentally tractable time.

1.3 The Desk: The First Step (Time of Humans Like Us)

The first 100 ky back in time cover 1 m, equal to an energetic stride. It also fits on the desk in front of the student (Fig. 3).

This period is dominated by the latest glaciation, named Weichselian/Devisian/Würm (Europe) or Wisconsinan (North America). Glaciers advanced and rainforests retreated through this period, except for the last about 12 ky ~ 12 cm, the Holocene.

Dramatic geo-events include the Toba eruption at 70 ky ~ 0.70 m which is hypothesised to have caused a dramatic cold spell of 6–10 ° for a decade, associated with dramatic impacts on vegetation and fauna. Thus, gene studies in several mammals (chimpanzee, orangutan, macaque, cheetah and tiger) indicate population bottlenecks around 70–55 ky ago. The same applies to the human genome, but the

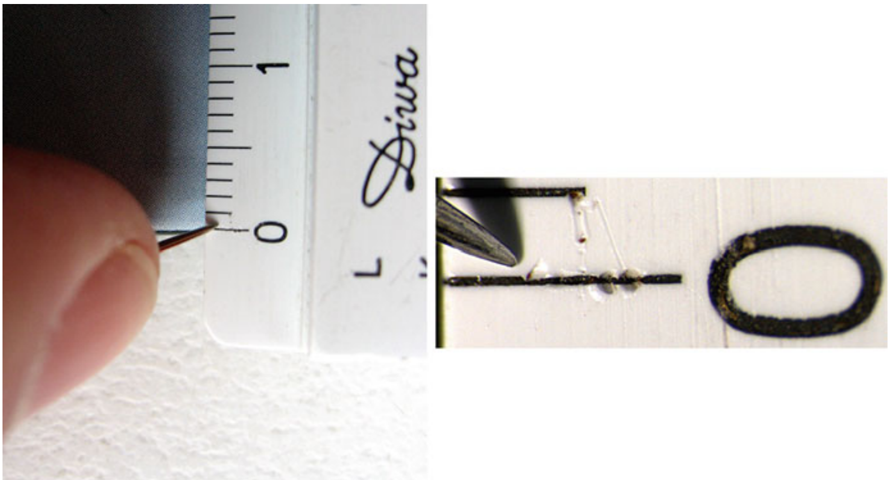

Fig. 1 At 1 mm per 100 years, you may imagine to mark the milestones of your life using a sharp needle

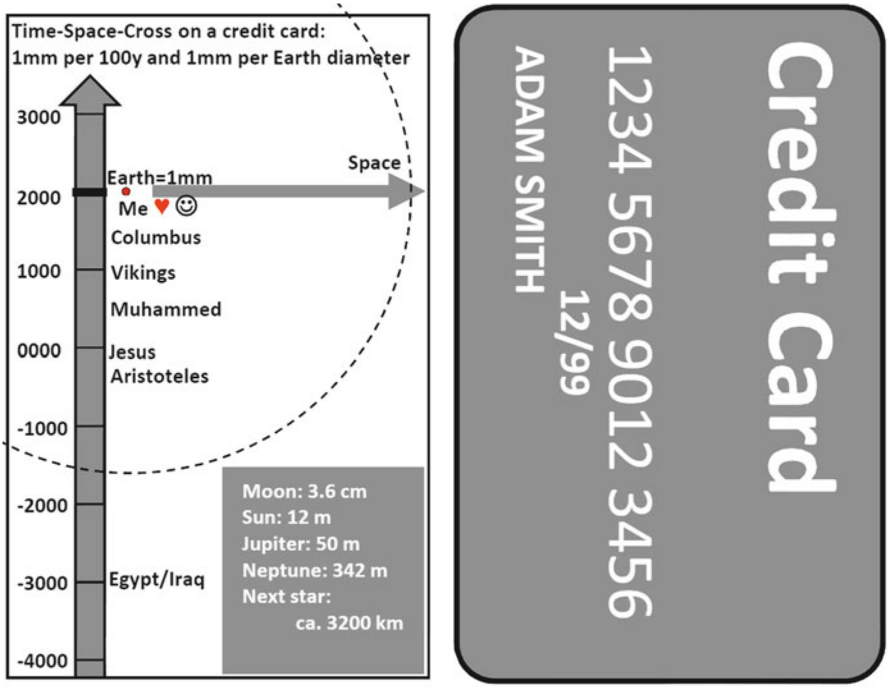

Fig. 2 The "TimeCard" maps all of history within the length of a credit card. The horizontal *black line* of width 1 mm shows the length of a healthy life as well as the last century of democracy and globalised individualism. The perpendicular space dimension is discussed in Sect. 2.4 on the installation of a time-space cross

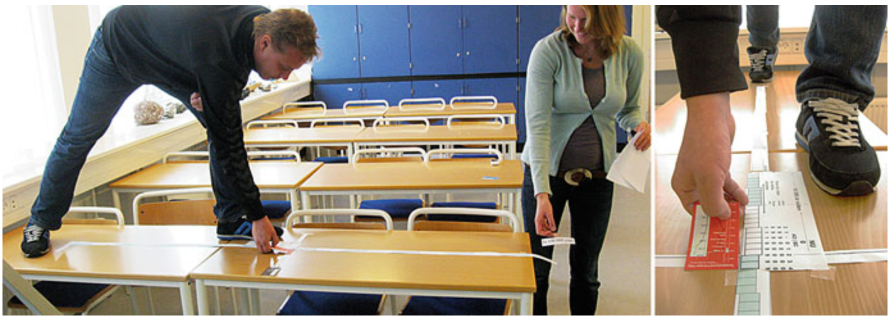

Fig. 3 *Boy left*: The first 100 ky back in time cover 1 m. This is the interval in time when *Homo sapiens sapiens* evolved and spread over the globe. Girl holds the label "In 100,000 years". *Right*: The TimeCard is placed carefully at the now-time

timing of the bottleneck is less certain.[2] More certain it is that *Homo sapiens sapiens* spread globally in this period.[3]

This period also saw a dramatic decline of large mammals, coincident in time with the outflow of modern man from Africa and development of specialised large-game hunting cultures. In this short period, geologically speaking, more than half of all mammals over 10 kg disappeared, and all land species above 1,000 kg outside Africa became extinct.

So, "the desk" maps the time of extinctions in mega fauna, including Neanderthals, and the rise of modern man, *Homo sapiens sapiens*, people like us in probably all respects capable in complex language, rituals, technology, complex societies and organised religion.

1.4 Through the Classroom and into the Hall: The Quaternary, the Time of Homo Erectus and Latest Swarm of Ice Ages

Since 2.6 My ~ 26 m, global temperature started fluctuating with an erratic but quasi-periodic rhythm of 40–100 ky ~ 0.4–1.0 m. Relatively long quasi-regular glaciations with spreading ice caps, drier climates and lowered sea level alternated with relatively short interglacial warm periods.

The action of large glaciers accelerated erosion and sediment redistribution dramatically, sculpturing landscape and subsurface down to hundreds of metres over whole subcontinents. Mountain ranges like Norway and Greenland were deeply eroded as fjord landscapes, resulting in hundreds of metres of long-lasting isostatic uplift, whereas surrounding areas received tens and hundreds of metres of moraines, loess and alluvial fans.

Mammals experienced a high evolutionary pressure, also in warmer climate zones. Hominids evolved with the emergence of *Homo erectus* at 1.8 my ~ 18 m and with control of fire and cooking from perhaps the same time (Wrangham 2009).

But why did the climate fluctuate so much and so regularly during the Quaternary? The common wisdom goes as follows: The average insolation has varied at different latitudes owing to the orbital oscillations, named after Milutin Milanković. The average insolation in July at 65 ° northern latitude, in particular, is believed to be the main driver of glaciations. This curve, which is shown in Fig. 4, is available also as a 160-page pdf file for mapping of this climatic driver along a timeline in the classroom and down the hall.

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[2] http://en.wikipedia.org/wiki/Toba_eruption

[3] http://en.wikipedia.org/wiki/Early_human_migrations

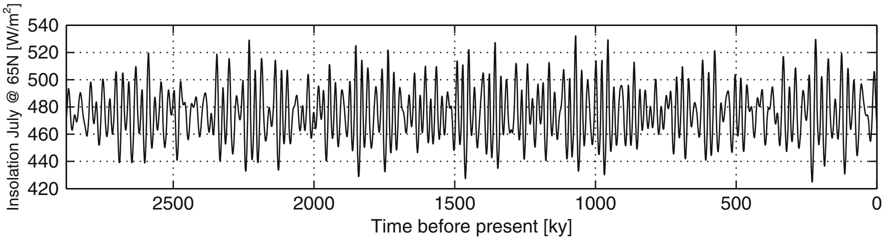

Fig. 4 The Milanković massage of climate during the Quaternary. The curve shows average insolation in July at 65 ° north. Summer temperature at this latitude is believed to be critical for tipping points in snow-albedo–cooling-snow feedback. In effect, global climate has changed every 40–100 ky (Data computed with computer code la 2004; see Laskar et al. 2004). Before the Quaternary, the Milanković driver was equally strong but, for reasons not completely understood, it did not trigger glaciations

1.5 Along the Village or a Few Blocks: Age of Mammals and the K–T Event

Next stop in time for the average educated citizen is the extinction of dinosaurs at 65 My ~ 650 m, at the K–T event. So, the timeline through the Cenozoic down to the beloved dinosaurs[4] will run outdoors close to school or home, yet being within the on-foot home ground of typical primary-school children.

However, as teachers, we would want to put in a number of important stops and intervals between the Quaternary and the K–T event. Some milestones for the teacher to convey could be:

33 My ~ 330 m: *The Eocene–Oligocene global cooling*. Antarctica freezes over. Since then climate shows persistent fluctuation, and climate zones as we know them establish. About the same time, the Himalayan orogeny changes the atmospheric circulation pattern and lowers CO_2 through erosion chemistry.

55 My ~ 550 m: *The Palaeocene–Eocene Thermal Maximum* (*PETM*). A dramatic global warming event (~6 ° warming over perhaps 1,000 years) is followed by extinctions at sea but most remarkably also by the rapid diversification and radiation of placental mammals, except for the isolated continents of Australia and South America. See also the “growth theme”, Sect. 3.3.

58–52 My ~ 580–520 m (overlapping with PETM). Temperature rises globally by about 4 ° over a period of 6 million years, i.e. less than 1 ° C per million years or 1,000 times slower than the PETM. Tropical climate prevails over most of the globe, and crocodiles live in Greenland. Note that this is not due to continental drift. Greenland is still at high latitude. See also the “change theme”, Sect. 3.4.

65–55 My ~ 650–550 m: *The Palaeocene*. Life recovers after the K–T event; small mammal forms increase in number and size but are still primitive.

[4]Never underestimate the fascination power of dinosaurs. A boy age 6 was asked if he knew a word starting with a B. “No”, he said, pondering, and then broke out “Brachiosaurus”.

This story of the age of mammals (actually three parallel stories if you count also Australia and South America) is mapped into the village or the few blocks defining the neighbourhood of the school/university or home.

1.6 A One-Hour Walk: Age of Footprints (Life on Land)

Animals went on land about 390 My ago. Details can be debated, but this important milestone lies at about 3.9 km, which is reachable on foot in an hour or less, leaving time for discussions and perhaps even a bus ride back.

Additional highlights are:

95 My ~ 0.95 km: *Very high levels of* CO_2, temperature and sea surface characterise the late Cretaceous time. Dinosaurs are common even near the South Pole.

250–65 My ~ 2.5–0.65 km: *Mammals in the dark*. Dinosaurs reign; mammals struggle as small night animals, developing warm blood and feelings.

260–250 My ~ 2.6–2.5 km: *The great dying*. The 95 % mass extinction at the boundary between the Permian and the Triassic is really horror material. Mammals lose; dinosaurs come out on top.

340 My ~ 3.4 km: *The first dry nest*. Eggs develop the capacity to keep water on dry land and to deal with the metabolic waste products accumulating in the egg while developing. Reptiles and mammal ancestors can now spread into the continents.

1.7 A Day Trip by Bike: Age of Life and Earth

The origin of the solar system and early Earth is around 4.6 Gy, which is 46 km away. This is reachable in some hours by bike.

The beginning of the solar system and Earth is a relatively condensed story. The development from a structureless star nursery of gas and stardust to the isolated, rotating star nebula of the early solar system may have happened in just 100 ky ~ 1 m,[5] and the subsequent formation of planetesimals large enough for internal melting by radiogenic heating formed after just 1–3 My ~ 10–30 m. Early Earth is almost ready by perhaps 50 My ~ 500 m, after the catastrophic collision leading to the Moon formation. So this important early history of Earth happens over a "surprisingly" short period.

Additional highlights, in very round figures and focusing on life, are:

1 Gy ~ 10 km: *Multicellular life*
2 Gy ~ 20 km: *Cells with nucleus and organelles*
4 Gy ~ 40 km: *First bacteria*

Also the grand stories of the "Late Heavy Bombardment", the Huronian megaglaciations and Snowball Earth should be told for this interval of time.

[5] http://www.ukaff.ac.uk/starcluster/

1.8 A One-Day Excursion by Car or Train: Age of the Known Universe and the Big Bang

The Big Bang is around 13.7 Gy or 137 km away. This is reachable in a few hours by car or train, thus suitable for a one-day excursion.

As for the Sun/Earth/Moon origin, the Big Bang is a place with rapid changes.

400 ky ~ 4 m *after the Big Bang: Release of microwave background*. Plasma recombines at a temperature of 3,000 K and releases the cosmic microwave background radiation, a nice yellow colour like a tungsten bulb, which cools down to 2.7 K as the universe expands.[6]

13.6–12.7 Gy ~ 136–127 km: *Light comes to the universe*. Galaxies form and first stars start to shine, probably also the Milky Way.

12.7 Gy–present ~ 127–0 km: *Stardust fertilisation of the galaxies*. Supernovas continuously enrich galaxies in heavier elements, required for rock planet formation and life as we know it.

From an Earth science point of view, this interval is rather meagre in other highlights to pinpoint. However, origins of famous stars could be mapped. The visible bright stars tend to be rather young, so they are born long after the origin of the solar system. Stars with Earth-like exoplanets will become the famous stars of the future. These stars may be old.

1.9 Mapping and Travelling the Deep Future: The Real Challenge to Imagination

After having worked with deep time in the past, it becomes so obvious that time will also continue into a similar deep future. The important difference is, of course, that our knowledge of the future is incomplete, not just because we are not clever enough or lack accurate data. The future is in a more fundamental sense not determined because it will be influenced by human choices. This indeterminacy makes modern citizens much less willing to consider and discuss future life conditions. Still, there are a couple of things we can say scientifically about the future, not just the next few years where climate models can predict warming scenarios, and GPS measurements can predict plate motion and energy build-up in earthquake zones.

The first metre into the future contains some likely events:

Twenty-first century ~ next millimetre: *Non-carbon energy*, "*perfect*" *recycling of metals and stabilisation of biodiversity*. We may discuss how soon it will happen, but it is unlikely that humans will accept, decade after decade, the consequences of growing fossil energy consumption, shortage of metals rarer than iron and aluminium and loss of biodiversity as we know it.

[6] http://en.wikipedia.org/wiki/Timeline_of_the_Big_Bang

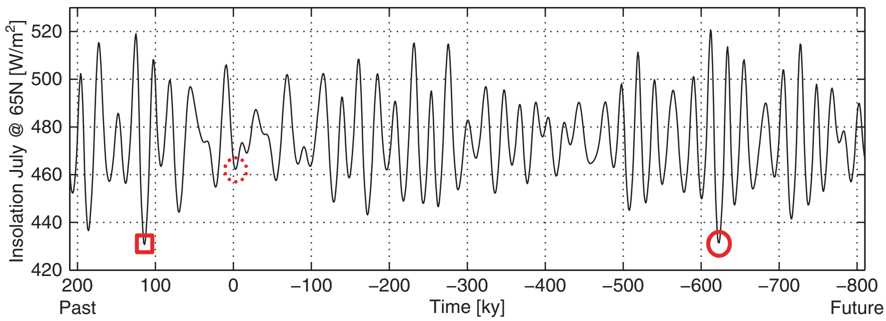

Fig. 5 July insolation curve for 65 ° north, running from 200 ky in the past to 800 ky in the future. Low values of insolation may trigger ice ages. The rectangle marks the level which ended the Eemian and triggered the latest glaciation. The *dotted ellipse* shows that insolation is relatively low now and some 1,000 years into the future, so a new ice age may be triggered. However, the insolation is much higher than at 110 ky in the past, and the same applies for all minima until 620 ky in the future (*full-drawn ellipse*). So, the next ice age may be far away

Next millennium ~ next centimetre: Groundwater cleans up naturally? If pollution of groundwater is stopped soon, then natural groundwater flow will flush most subsurface reservoirs now being polluted.

AD4000 ~ 2 cm: *Greenland ice cap almost gone*? If climate is stabilised some degrees above present, then the Greenland ice cap will continue melting. However, it will take one or two millennia before most of the ice has gone. The associated sea-level rise of 7 m will be spread in time accordingly, i.e. about 0.4 m/century.

10 ky ~ 10 cm: *Strong drift in human genome*? If mating and family size remains a private affair, then even small preferences towards mental or body characteristics will show up very clearly after these 300 generations. In particular, the mental characteristic of "liking children" will probably become much more widespread.

100 ky ~ 100 cm: *Denmark half gone*? Though a detail in the context of global change, it should be noted that normal coastal erosion is about 1 m per year along the Danish west coast. If coastal erosion is not controlled, then 100 km of the Danish mainland will be gone after 100 ky.

1 or 630 ky ~ 1 cm or 6.3 m: *The next ice age*? The mechanics of the solar system is well understood, so the insolation curve mentioned in Sect. 1.4 has been predicted into the future as well. The insolation from 200 ky ago to 800 ky into the future is shown above (also available as pdf in the correct scale). The box indicates the low insolation that ended the Eemian and started the latest Weichsel/Wisconsin glaciation (Fig. 5).

Clearly, the next millennium is a danger zone because of the relatively low insolation. The Little Ice Age 1500–1800 AD may have been a warning. However, this insolation minimum (dashed ellipse) is not very low compared to the previous glaciation trigger. Because of the small ellipticity of the orbit, the next ~100 ky will show rather small variations in insolation, so the next low at 65 ky is not very deep either. In fact, the next really deep insolation minimum is 630 ky from now (ellipse), so we may be facing an interglacial period of more than 600 ky, even without anthropogenic global warming.

The immediate surroundings of a NowGate (see Sect. 2.1) will typically be adequate for installation of this "near future".

Regarding the more distant future, we can say that for what we know about the physics and chemistry of our planet and its Sun and neighbouring planets and stars, there is no reason why we should not have a very similar Earth for at least some 100 million years. Moreover, for this period, we even have reasonably accurate ideas of how subduction zones and volcanism and hence topography will develop:

100 My ~ 0–1 km: *Earth as we know it*. With the concluding word of Voltaire's Candide, "We must cultivate our own garden", we can say that, for at least the next kilometre along our timeline, we should expect the presence of a global garden for us to cultivate wisely, a garden more or less like we have known it as *Homo sapiens sapiens*. Large meteor impacts may be a threat, so meteorite defence is a nice tale to tell for this period. Technologically, it is within reach already, but we should obviously not develop meteorite steering before all tendencies of suicidal thought and tribal aggression are understood and under control in *Homo sapiens sapiens*. And we should keep some large meteorites for later solar system engineering (see Boiling Earth below).

100–500 My ~ 1–5 km: *Warming Earth, insolation grows up to 5 %*. The gradual ageing of the Sun leads to increased insolation, which gradually leads to warmer climate on Earth. We may end up having tropical climate near the poles, but this insolation-driven warming will be very slow, say less than 0.1 ° per My. Life will easily adapt by natural evolution.

500–1,000 My ~ 5–10 km: *Boiling Earth, insolation grows up to 10 %*. We enter a phase where increased evaporation of the potent greenhouse gas H_2O may lead to a runaway effect whereby conditions on Earth will change to Venus-like conditions rather quickly, like the PETM (see Sect. 1.5), just 10–100 times worse. Perhaps the most thermophile bacteria may find a refuge somewhere, but basically we should regard this event as end of life on Earth. It is likely that ultraviolet dissociation of water vapour will lead to loss of hydrogen and hence loss of all our water shortly after or shortly before the H_2O-driven greenhouse runaway. The final effect will be same.

Should humans be around, this will be the period of solar system orbit engineering when it is, in principle, possible to move planets around slowly, so that Earth remains in the habitable zone for much longer (e.g. Korycansky et al. 2001) Also terraforming of other moons and planets is a fascinating tale to tell for this period. But note that solar system engineering does not seem to be a necessity before these 5–10 km down the timeline.

3–4 Gy ~ 30–40 km: *Likely collision and merging of Milky Way and Andromeda*. The date of this awesome 1,000 My long event is still uncertain. It may lead to a rise in heavy star formation and hence more frequent supernova explosions and gamma glimpses which may threaten life. More importantly perhaps, the ensuing gravitational turbulence may hurl the solar system outside the new galaxy, which may make later interstellar transits more difficult. Interstellar transit is thus a fascinating tale to tell for this stage in deep future. But note that interstellar transit does not seem to be necessary before some 30–40 km down the timeline of deep future.

5 Gy ~ 50 km: *Evaporating Earth, Sun enters red giant phase and Earth evaporates*. Like the K–T event in the past, this apocalyptic event is well known to most citizens. Should life still be around in the solar system, this phase will require "frequent" changes of hosting planets/moons. After the red giant phase, the Sun will be a very weak energy source, and no planets will be left close enough to carry life.

5–1,000+ Gy ~ 50–1,000+ km: *Era of red dwarf habitation*. The ultimate fate of the universe is the "heat death", a terribly slow universal apocalypse which has bothered both the general public and philosophers (cf. Kragh 2008). Yet, this "heat death" will in reality be very far in the future. Red dwarfs will provide a strong source of entropy, i.e. high-temperature energy in a cold universe for a long time. For this period, red dwarf habitation is an interesting tale to tell; plans for their habitation are already developing.[7]

Thus, this timeline puts into a quantitative perspective the different events and processes to be expected scientifically in the deep future, and it helps the citizen understand that the many threats to life and civilisation do not have to be dealt with soon, nor at the same time. There is an ocean of time for wise cultivation of this wonderful garden in our hands.

2 Examples of Time Installations

The description of the timeline above may be useful as it is, but realisation of the full pedagogical effect requires a physical and/or virtual installation in the surroundings of the pupil/student/citizen. I will first consider the very important point where the past meets the future – the NowGate. Then, I describe in detail three installations with rising level of complexity.

2.1 The NowGate

The TimeCard (Figs. 2 and 9) may be placed on the floor where we want to define the NowLine. As a dramatising physical element, it is straightforward to erect a "door to the future" or NowGate at this point. Figure 6 shows such a primitive mobile installation equipped with replaceable paper through which a daring person "jumps into the future" to the applause of spectators.

[7] http://en.wikipedia.org/wiki/Habitability_of_red_dwarf_systems

Fig. 6 NowGate implemented as a simple frame with paper through which a person can "jump into the future". This boy landed 80 ky ahead of his time. Note labels on floor every 100 ky ~ 1 m and diagrams

On the floor, we may place paper labels for every 100 ky ~ 1 m, marking time in intervals of "humans like us on Earth". Case 1 placed these labels over the first 130 m inside a building. Case 2 placed also chalk marks for every metre back to 390 My (see Fig. 10).

2.2 Case 1: Physical Installation of Cenozoic + Upper Cretaceous Time on Campus (2008)

The first test installation was performed on the Aarhus University Campus, as part of a natural science fair open to the public. The NowGate was one of the stands of the fair, and the timeline ran all through the fair area with labels every 100 cm, saying "700,000 years ago" etc.

Outside the building, the line continued with 30 cm tall white pegs every 1 My ~ 10 m. Milestones like "25 My: Apes separate from other primates" were illustrated and mounted on the pegs. The timeline was placed so that 650 m coincided with the campus amphitheatre which could therefore play the role of the K–T impact crater. The timeline was only installed physically inside the campus area which covered the latest 100 My, i.e. including Upper Cretaceous. From there, a sign just

Fig. 7 The Case 1 TimeLine is positioned so that the origin of life and the Big Bang, respectively, happen at two locally famous landmark sculptures which are traditionally also understood as representing admirable characteristics of the native population

informed that the origin of life and the Big Bang coincided with Jutland's Stallion[8] and the Cimbrian Bull,[9] landmarks of the town of Randers and the town of Aalborg, respectively (Fig. 7).

2.3 Case 2: Integrated Physical and Virtual Installation of Time at COP15 Using Google Earth and YouTube (2009)

This second installation was much more complex. It ran for a week during the COP15 climate summit in Copenhagen mid-December 2009. The elements described above in Case 1 were supplemented by a virtual installation for Google Earth and a primitive web repository for digital material.

The elements in the installation were termed TimeCard, TimeWalk, TimeLine and TimeTalk (Fig. 8).

2.3.1 TimeCard

The TimeCard advertised the installation and pointed to the location of NowGate.

In line with the themes of COP15, three different TimeCards were developed where CO_2 levels, temperature and sea levels were integrated with historical events (see Fig. 9). The TimeCard was used as hand-out together with the one-page folder described below.

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[8] http://www.kantate.dk/den_jyske_hingst.htm

[9] http://www.visitaalborg.com/danmark/da-dk/menu/turist/oplevelser/attraktioner/monumenter/produktside/gdk011879/cimbrertyren.htm

Fig. 8 Geographical location of the installation during COP15. *Left*: The whole line with the Big Bang starting at "Land of Legends" near Roskilde, origin of Sun and Earth at Kronborg Castle and (*right*) the Phanerozoic as a walking track near the inner harbour of Copenhagen, including the Little Mermaid as the position where vertebrate life went on land

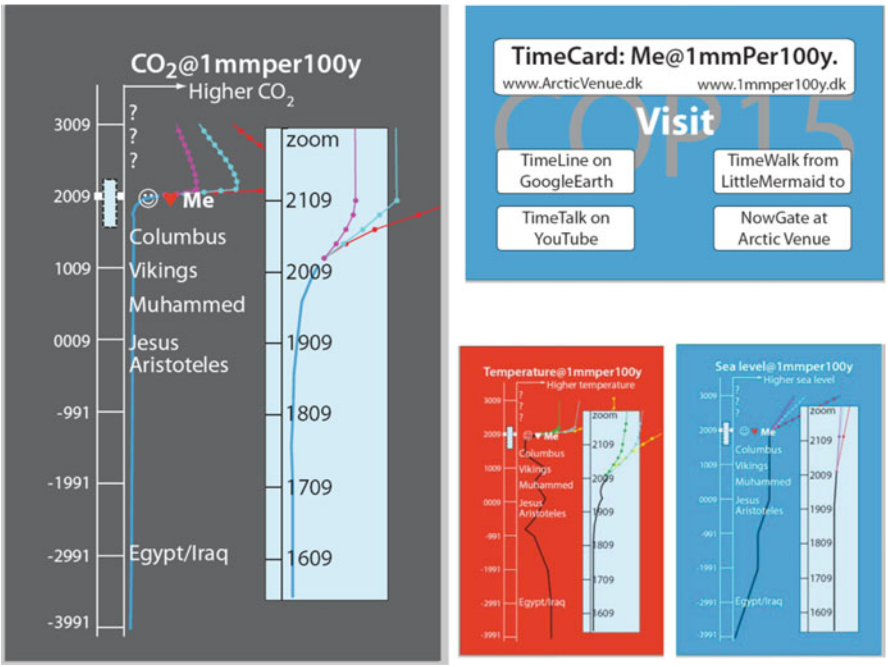

Fig. 9 TimeCards for the COP15 installations emphasised changes in CO_2 level and related climate variables through historical time and the next millennium

Fig. 10 *Left*: Starting point of TimeWalk at 390 My where vertebrate life went on land, coincident with the Little Mermaid. *Chalk circles* divide the walk into metre intervals, i.e. the time of *Homo sapiens sapiens*. *Right*: The CARBONateFOOTPRINTer allows convenient deployment of footprints

2.3.2 TimeWalk

The latest 390 My cover "the age of footprints" in the sense that animals had set their feet on land. An A4 folder in Danish and English was produced and distributed in boxes (circled in Fig. 10, left) along the walking route located in the inner harbour of Copenhagen. The TimeWalk was marked with the CARBONateFOOTPRINTer (see Fig. 10 right) with which chalk circles could be placed every 1 m ~ 100 ky. A total of 3,900 marks were deployed in order to cover "the age of footprints" back to the first animals believed to leave the first footprints on land. These real-life mermaids were coincident with the national landmark sculpture The Little Mermaid. Sure she is prettier, but Tiktaalik had what she wanted: four legs!

Another landmark involved was the Gefion Fountain, which shows the four bulls with which the Nordic goddess Gefion ploughed out the island of Zeeland from Sweden. This landmark was located where the reptile egg was developed, i.e. up to this point, breeding required eggs to be submerged in water. The continuous spraying of the four bulls illustrated this condition.[10]

2.3.3 TimeLine

The track of time was installed carefully as a path (see Fig. 8), and a kmz file for Google Earth was produced with numerous place marks. This kmz file could be downloaded from the project website www.1mmper100y.dk.

The Big Bang was located at "Land of Legends", an outreach park for archaeology. It is also very close to excavations of the dwellings of the first named kings of Denmark. First stars and galaxies were located at the Viking ship museum in

[10] http://en.wikipedia.org/wiki/Gefion_Fountain

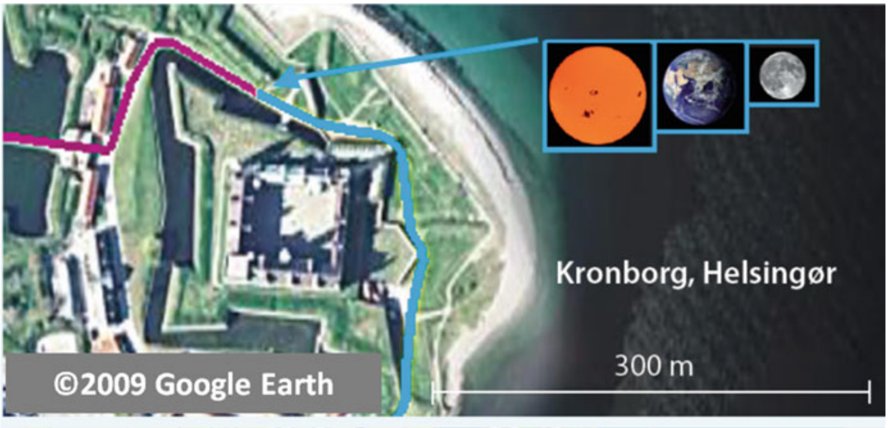

Fig. 11 The details of solar system formation and Earth and Moon accretion is mapped out around the outer defence wall of the national symbol and UNESCO World Heritage Site, Kronborg Castle in Elsinore

Roskilde, and the origin of the Sun, Earth and Moon was mapped out in detail around the Castle of Kronborg in Elsinore, which is a landmark of national pride, the supposed scene of Shakespeare's Hamlet and UNESCO World Heritage Site number 696 (see Fig. 11).

The TimeLine continued past TimeWalk into the future towards the Bella Centre, venue of the COP15 meeting, and further into the highway system south of Copenhagen.

2.3.4 TimeTalk

Primitive video narratives were recorded "on location" at 25 points along the TimeLine. These video narratives were accessible from www.1mmper100y.dk and to some extent also on YouTube and linked to the Google Earth kmz file.

This integrated installation was perhaps a bit too complicated, given that it was only on display for a few cold, moist and windy December days during the COP15 meeting, but as a test of concept, it was very useful.

2.4 Case 3: Installation of Time-Space Cross at the Science on Stage Festival (2011)

This installation had its NowGate moved slightly within the Copenhagen area, to the venue of the Science on Stage Festival 2011,[11] so most of the virtual installation from Case 2 could be maintained.

[11] http://www.science-on-stage.eu/

As something new, it was attempted to include a perpendicular space direction (see Fig. 1). The scale factor was chosen in the following way:

During the lifetime of a modern citizen, it is not uncommon to make one global travel on average. So, in the same spirit invoked for the time dimension, the distance 1 mm is taken as the diameter of the Earth, whereby the realm of one human life is this square millimetre in time and space.

Real distances in space are divided by 12.7×10^9 so that the distance to the Moon becomes 3 cm, Sun at 11.8 m, outer solar system between Jupiter at 50 m and Neptune at 342 m and next star at 3,200 km.

The scaled space dimension was also installed virtually on Google Earth as a path with place marks so that the inner solar system fitted inside the venue of the Science on Stage Festival ("in the classroom and down the hall"); the outer solar system fitted the immediate neighbourhood reachable by casual walk, but then there is emptiness. To get to the next star, we would need to walk 100 days at 32 km/day or travel by airplane for about 4 h, and it would take 8–10 years of continuous jet plane flying to get to the centre of our galaxy.

These space proportions inside the solar system have been illustrated in several "planet walks" or "planet paths" around the world, using different scale factors. The time-space cross proposed here has the extra feature that time and space are scaled "in the same way", i.e. one square millimetre contains the life path of the citizen. Moreover, the tales to tell when going into the deep future (Sect. 1.9) about transits away from Earth get a strong perspective when associated with the scaled space dimension. Clearly, there are serious quantum jumps from Moon to planets, from planets to nearby stars, and from nearby stars to other regions of the galaxy, not speaking of intergalactic transits.

The scaled space dimension is much less "graspable" than the scaled time dimension which has a lot of stops to visit with fascinating animals and events highly relevant to our present life and environment. It is doubtful whether it provides a real understanding of space proportions to know that if you scale the Earth to a millimetre, then you must fly for 9 years to reach the centre of the galaxy, 170 years to reach Andromeda and a million years to reach the most distant galaxies. To me, the feeling remains as expressed by Blaise Pascal (1623–1662): "The eternal silence of these infinite spaces fills me with dread".

But it does tell us that the universe is larger than it is old.

3 Games to Play and Exercises to Solve in Time

This section contains merely a sketchy list of activities where the learning and understanding of time can be aided by this single-scale timeline. Most teachers will probably come up with different and better ideas of their own.

3.1 Tracking a Virtual Installation by GPS on Smartphone

The simplest and least demanding utilisation of the timeline is to install it in virtual form with locations and explanatory material and download it to the students' smartphones. Then, they can take the tour themselves or just relax in the back of the car or the school bus with a parent, a teacher or others driving. The installation could be adjusted so that the now-point and possibly also the Earth origin and the Big Bang are located at parking places or cafeterias along the route so that the event-packed tens of metres can be done safely on foot.

3.2 School Class Studying the Phanerozoic

Depending on local geology, a school class may target some interval of the Phanerozoic, like the Cretaceous, if the school is in a chalk mining area, or the Carboniferous if in a coal mining area. Then the class could map out the timeline from their classroom to the relevant position and make a more detailed installation of the specific geological and paleontological events around this location.

If choosing to study the Phanerozoic more generally, the class could divide into project groups distributing epochs/periods between them. When the exhibition material is ready, each group installs its period/epoch properly along the 6 km long path. The class, and possibly also parents, walks this path together, and each group tells the tale of their period/epoch to the others. Obviously, modern students may well, all by themselves, integrate video narratives and other digital material on a virtual platform like Google Earth.

3.3 Playing with Growth and Interest

Growth is the essence of life and of human economic thinking as well, both individually and socially. For a child, a physical growth rate of 1 % per year is very little. The same is thought for economics. Yet, when working with growth over the time spans of just 1,000 years, a rate of 1 % per year implies an accumulated growth factor of more than 20,000. Such games show things like:

- If involving materials, an economic growth rate of 1 % is essentially impossible when planning deep existence.
- Even a small annual growth in one species/population relative to another will lead to complete dominance of the growing species/population in a relatively short time. Thus, the Neanderthal tribes may not have seen much change over a lifetime, yet their exit developed fast compared to archaeological resolution.
- The gradual deterioration of life conditions in the deep future, say Boiling Earth, will not require evacuation of a fully populated Earth. If each generation reduces the population by 1 %, we will be down to a few people after 2,300 generations, i.e. 70 ky. Still, such a plan would look grim for the remaining reverse-time Adam and Eve, but perhaps their space-borne relatives could evacuate them.

3.4 Amounts of Change and Rates of Change

Discussions of anthropogenic changes in climate, biodiversity and material reserves often involve comparisons to natural changes in the past. Such discussions can be supported by learning games involving comparisons of natural and anthropogenic *rates* of change.

Temperature: In Sect. 1.5 on the Cenozoic, we saw a temperature change of about 6 ° in just 1,000 years at the PETM. This is perhaps the fastest prehuman temperature rise. The rate is about 0.6 ° per century. This rate is similar to the rate of anthropogenic warming we see now. This temperature increase rolled back again over a period of about 200 ky, i.e. a rate of only 0.003 ° per century.

A more gradual temperature change of about 1 ° per million years persisted for about 6 million years. The amount of change was the same as the PETM, but the rate of change was just 0.0001 ° per century.

Material cycles: The amount of CO_2 drawn down in chalk deposits of the Cretaceous is enormous. Under the small Danish area alone, the Upper Cretaceous deposits bind more than 10 times the total global anthropogenic release of fossil carbon so far. Yet, the flux of CO_2 to these deposits during the Cretaceous was about 50,000 times smaller than the anthropogenic release rate of CO_2 in 2010.

An enlightening exercise is to draw the graphs of such changes on paper in the proper scale (or perhaps give up when the student realises the amount of paper required). The pdf files with the Milanković insolation driver may serve both as example and as a template on which the student can draw other changing quantities. The TimeCards from Case 2 (Fig. 9) illustrate this for the historical past.

3.5 Looking Back From the Future: A Defining Ethical Moment?

From an ethical point of view, it is a most striking personal experience to stand at a distance of 1–2 m ~ 100–200 ky into the future discussing this “near” future and the present. Looking back at the TimeCard at the NowLine and considering the long-lasting effects on biodiversity and other life conditions which are playing out over the next “millimetre”, it becomes rather clear what ethical obligation this generation has. Difficult choices and decisive actions suddenly seem so natural.

4 Joining the www.1mmper100y.dk Project

Obviously, the ideas presented here are easily transferred to other geographical locations. I have indicated how local landmarks, waterways and topographical elements can be used pedagogically as mental anchors and associations.

Teachers or students producing a TimeLine elsewhere at the scale of 1 mm per 100 years are most welcome to submit the kmz or kml file as well as other accompanying material to this author so that it can be made accessible on www.1mmper100y.dk. However, a requirement is that this scale is respected within ~10 %, and that all material is scientific in character.

Overview

Background and Motivation

– Understanding time: In journalism, public debate and politics, much confusion is due to lack of a proper scientific understanding of time proportions, particularly when it comes to the future. This project develops ideas for installations of time as a path in space. These learning tools aim at all citizens, from pre-school to academic level.
– Test of installation ideas: This project did not comprise tests of pedagogical impact of the proposed learning tools. The objective was mainly the development, testing and documentation of the installation ideas.

Innovations and Findings

– One time: It is tempting to scale time differently so that different subjects like history and geology can plot their graphs on the same size paper or blackboard. The pedagogical cost is that students have difficulties relating deep time and historical time. This project emphasises that there is only one timeline, containing individual life projects as well as cosmological evolution stages and what lies in between. The specific scale of 1 mm per 100 years is chosen so that deep time is mapped into a geographical area where young citizens already understand space proportions well.
– Easy mental calculation: The scale 1 mm per 100 years implies easy calculations of locations of events and periods in time.
– Three examples of installations have been tested, ranging from the simple physical installation of a past-to-future time walk to complex integration of exhibition of a NowGate, a physically marked time walk, a Google Earth virtual installation of the full timeline and video narratives.
– “One timescale” is easier than “one space scale”: The 1 mm per 100 year timeline seems more tractable and pedagogically rich compared to the 1 mm per Earth diameter space line which has much larger scale differences.

Implications for Wider Practice

– Developing installations: Clearly, the presented installations and associated student activities can be easily transferred, developed and shared on the web.
– Deep responsibility: A bold vision of this project would see numerous young people taking shared ownership of their deep history, their deep future and their implied obligations in present politics and personal conduct.

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Part V
Programme Design

Integrating Geoscience Research in Primary and Secondary Education

Elena B. Sparrow, Leslie S. Gordon, Martha R. Kopplin, Rebecca Boger, Sheila Yule, Kim Morris, Krisanadej Jaroensutasinee, Mullica Jaroensutasinee, and Kenji Yoshikawa

1 Introduction

Many of our twenty-first-century science, technology, engineering, and mathematics (STEM) challenges such as climate change involve the geosciences. Solutions to these challenges will require a scientific workforce that is armed with a robust, complex skills set to facilitate the integration of interdisciplinary concepts and bold technologies to increase knowledge of both global and regional-scale geophysical

E.B. Sparrow (✉)
The International Arctic Research Center, The School of Natural Resources and Agricultural Sciences, University of Alaska Fairbanks, Fairbanks, AK, USA
e-mail: ebsparrow@alaska.edu

L.S. Gordon
Science and Math Education, Gordon Consulting, Neskowin, OR, USA

M.R. Kopplin
The International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK, USA

R. Boger
Earth and Environmental Sciences, Brooklyn College, New York, USA

S. Yule
Science Education, National Energy Education Development Project, Louisville, KY, USA

K. Morris
Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK, USA

K. Jaroensutasinee • M. Jaroensutasinee
Center of Excellence for Ecoinformatics, School of Science, Walailak University, Nakhon Si Thammarat, Thailand

K. Yoshikawa
Institute of Northern Engineering, University of Alaska Fairbanks, Fairbanks, AK, USA

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phenomena and address related issues. Demographic studies indicate that throughout this century, the US minority population will become its majority, and statistical data (Huntoon and Lane 2007; Gonzalez et al. 2009) confirm underrepresentation of the current minority population in STEM disciplines in general and in the geosciences, in particular. There is also a lack of basic STEM competencies across broader workforce sectors, and according to researchers in this field, about 30 % of jobs in the entire labor force in the future will require basic STEM skills which the current supply of workers lack (Carnevale et al. 2011). In preparing a scientifically literate and competent workforce, efforts need to begin in primary and secondary education to improve the quality and rigor of geosciences teaching in precollege classrooms (Barstow and Geary 2002; Stevermer et al. 2007) and in the preparation of teachers in these classrooms (Hoffman and Barstow 2007).

The Monitoring Seasons Through Global Learning Communities project, also known as Seasons and Biomes (SAB), integrates earth system science and environmental research in the teaching and learning of science in primary and secondary schools. Seasons and Biomes is among the IPY education outreach projects approved by the IPY Joint Committee of the World Meteorological Organization and the International Council for Science. It is an inquiry- and project-based initiative that monitors the interannual variability of seasons and seasonal indicators in biomes. It connects Global Learning and Observations to Benefit the Environment (GLOBE) students, teachers, and communities with educators and scientists from earth system science programs such as the International Arctic Research Center (IARC) and NASA Terra and Landsat Data Continuity Missions and scientists from other countries. Seasons and Biomes is one of four earth system science projects in the GLOBE program (www.globe.gov).

GLOBE is an international environmental science and education program in more than 100 countries that brings together primary and secondary school teachers, their students, and scientists in earth studies (www.globe.gov; Butler and MacGregor 2003; Sparrow 2001). There are more than 54,000 GLOBE-trained teachers and their students from more than 20,000 schools who conduct studies at or close to their schools and enter their data on the GLOBE website. GLOBE has been and is currently being used for teaching science in schools and conducting professional development workshops for teachers (Bombaugh et al. 2003a, b; Gordon et al. 2005; Penuel et al. 2005).

Seasons reflect the dynamic nature of energy flow and biogeochemical and water cycling which link the atmosphere, biosphere, hydrosphere, cryosphere, and lithosphere components of the earth system. For example, global plant waves of green-up and green-down indicate fluxes in the carbon cycle. Changes in and timing of seasonal or phenological events are indicators of climate change and its impacts, and reflect the variations that are occurring in the flux of energy in the global environment. Seasonal change profoundly affects the balance of life in ecosystems in biomes and directly impacts essential human activities such as agriculture and subsistence.

A biome is a large terrestrial region defined by its climate, geography, and ecologically similar communities of plants, animals, and soil organisms that interact with the abiotic components of the environment. Biome types are also determined based on other factors such as vegetation types (trees, shrubs, grasses), leaf types (broadleaf, needleleaf), and plant spacing (forest, woodland, savanna). Descriptions of biomes can be found at http://wwf.panda.org/about_our_earth/ecoregions/about/habitat_types/selecting_terrestrial_ecoregions/

2 Motivation and Rationale

2.1 Goals and Objectives

The Seasons and Biomes program goals are to increase understanding of the Earth as a system, learn science as process and inquiry, contribute to earth system science and climate change studies, and participate in the fourth International Polar Year (IPY) and beyond. The significance of IPY and the polar regions to the global community becomes apparent when viewed in the context of Earth as a system where the different earth components are interconnected through the cycling of water and biogeochemicals and the flow of energy (Carlson and Salmon 2010). Changes in the polar regions affect other regions in the world and vice versa, since they are all interlinked in the earth system, e.g., changes in polar climate affect global climate and melting of polar glaciers affects sea level.

The objectives are to (1) engage primary and secondary students in earth system science research in their biomes, (2) provide teacher professional development in earth system science and inquiry aligned with the National Science Education Standards, (3) increase connectivity of precollege teachers and their students with scientists and community experts, and (4) build earth system science learning communities locally that connect globally.

By monitoring seasonal events and conducting inquiries in their local environment and biome, students learn how interactions within the earth system affect their locale and how changes in their biome may affect regional and global environments. Participating in the process of science is critical to the understanding and learning of science (Putnam and Borko 2001) as well as to teaching and learning of earth system science.

3 Methods

3.1 Approach

Seasons and Biomes uses several approaches to reach and engage primary and secondary educators and their students in geosciences research, the primary approach being through teacher professional development (PD) workshops. We conducted local, regional, and international PD workshops with workshops conducted in Alaska, USA, that were also offered as a 500-level University of Alaska Fairbanks course.

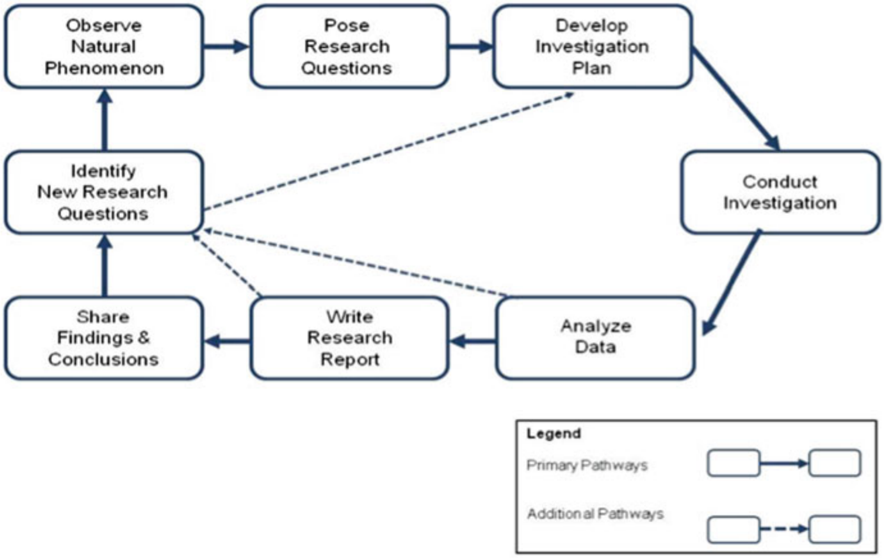

Fig. 1 Student scientific investigation model (Simplified from GLOBE 2012)

We developed a professional development (PD) workshop model for teachers/trainers and used a model for student scientific investigation (Fig. 1) that we codeveloped with a couple of GLOBE personnel. To engage students and their teachers directly, we conducted IPY Pole-to-Pole Videoconferences (Alaska, USA, and Ushuaia, Argentina), worked with GLOBE Alumni who facilitated web-based discussions (GS-Pals) among schools in different countries, and collaborated with GLOBE Africa on scientist-teacher-student actual and virtual expeditions to Mt. Kilimanjaro that has altitudinal belts of biomes. Virtual trekkers email their questions to the students, teachers, and scientists doing the actual expedition and get responses during the trek and afterward. Seasons and Biomes also partnered with the Australian Ice e-Mystery: Global Student Polar e-Books project; and the Ice e-Mysteries Polar e-Books: An Innovative Approach to Science and Literacy Education project, in the USA. This intercontinental collaboration paired 12 classrooms in Alaska, USA, and Tasmania, Australia, and conducted three PD workshops: one for the teachers in each country and then a joint one in Australia at the end of the science, literacy, and art project.

3.2 Professional Development Workshops: Implementation Support

During Seasons and Biomes PD workshops and in classrooms, scientists, local experts such as Native elders, and educators shared their knowledge with the teacher and trainer participants. Local knowledge and relevance to the locale provided a basis for environmental/earth science studies undertaken by teachers and their students. Seasons and Biomes and GLOBE provided the tools and infrastructure for observing, measuring, recording, and analysis of data and venues for communicating results (GLOBE Teachers Guide 2005; Butler and MacGregor 2003; Sparrow 2001). The best classroom teaching strategies such as teaching and learning through inquiry using a learning cycle model, teaching and assessing to national education standards and for diversity, and establishing a constructivist learning environment (Darling-Hammond 1997; Gordon 2001; Gordon et al. 2005) were modeled and practiced during the PD workshops and in the program. Culturally responsive science curricula (Stephens 2000; Assembly of Alaska Native Elders 1998) and the National Science Education Standards for professional development (Gordon et al. 2005; Gusky 2000; Loucks-Horsley et al. 1998; NRC 1996) were also used. Each time the PD workshops were refined according to the needs of the participants. Follow-up and ongoing support found to be key to classroom implementation (Gordon et al. 2005; Penuel et al. 2005) were provided through emails, phone calls, and visits; the latter two outside the USA were provided by the GLOBE Partners in the respective countries.

3.3 Measurement Protocols and Learning Activities

Interannual variability in seasons and seasonal indicators can be monitored by using parameters such as air and soil temperature, soil moisture, precipitation, vegetation phenology (budburst, green-up, green-down, arctic bird migration, etc.), ice seasonality, and depth of soil freezing. Standardized scientific measurements developed in GLOBE for investigations of the atmosphere (maximum, minimum, and current air temperature; amount of precipitation; cloud cover; cloud types; etc.), soils (soil temperature, moisture, pH, characterization of soil profile, etc.), hydrology (water temperature, pH, oxygen content electrical conductivity, etc.), land cover/biology (biometry, manual land cover mapping, computerized MultiSpec land cover mapping, etc.), and Earth as a system (phenology protocols) (www.globe.gov) were used. In addition, the Seasons and Biomes project developed ice seasonality protocols (freeze-up and breakup) for freshwater lakes and rivers (posted at www.globe.gov) with Kim Morris as lead, frost tube protocol (to measure the depth of active layer in soils underlain by permafrost or depth of frozen soil in soils without permafrost) with Kenji Yoshikawa as lead (www.uaf.edu/permafrost; Yoshikawa et al. 2013; Sparrow and Yoshikawa 2012), mosquito protocol (for dengue fever vectors) with Krisanadej Jaroensutasinee and Mullica Jaroensutasinee as leads (http://www.twibl.org/mosquito/download.html), mosquito protocol (for malaria vector) with Rebecca Boger as lead, and invasive plant species protocol with Kim Morris as the lead developer with Mark Brettenny and Rogeline Brettenny as initiators and now pilot testers.

Similar to the GLOBE program, Seasons and Biomes developed learning activities to help students understand the science concepts that are in the measurement protocols and to improve science skills. Learning activities include Getting to Know

Your Terrestrial Biomes, What Causes Seasons, Seasonal Leaf Change Inquiry, The Budburst Inquiry, Soil Insulation Inquiry, How to Make a Climatograph From Your Local Weather Data and How to Set Up an Ice Seasonality Site, and Exploring Our Data with Descriptive Statistics.

3.4 Evaluation Methods

Because of resource limitations and language barriers, most of the project evaluation activities we conducted were in participating schools in the USA.

3.4.1 Evaluation Related to PD Workshops

Results reported in this chapter are mostly for those held in the USA.

- Needs Assessment – teachers were asked to complete a written survey asking about their specific goals for attending each workshop we conducted. This occurred either before they arrived or at the beginning of the workshop.
- Pre- and Posttest Content Assessment for Teachers and Trainers – this instrument contains up to 11 items (depending on the length and focus of each workshop) on teacher/trainer understanding of Earth as a system, global climate change, and best practices in science education (inquiry learning, constructivism, teaching for understanding, and multiple intelligences). Each of the content and pedagogy items/responses to open-ended questions received scores of 0–3 (perfect score), and a rubric was used to score each item. Content validity was established using experts in the field and interrater reliability was established at 90 % (Wiersma 1995). This instrument was administered to each teacher on the first day and the last day of each workshop, and pre- and posttest data were statistically analyzed using paired *t*-test to determine the significance of difference between pre- and posttest content knowledge.
- Daily Fastwrites – these included formative assessment questions that were collected in writing at the end of each workshop day to determine how much teachers were learning. Some examples are as follows: “What is your understanding about making observations or asking a good research question, and why is it important to include in the model for student scientific investigation?” “What activity(ies) is/are beneficial today and why?” “What are your questions and concerns?” Fastwrites also help determine whether there are issues that need to be addressed the following workshop day.
- Final Teacher/Trainer Participant Survey – this was used to determine how beneficial each workshop component was to the participant and administered at the end of each workshop as part of a summative assessment. A Likert scale was used to rate each component from one (least beneficial) to ten (most beneficial).

3.4.2 Evaluation Related to Implementation in the Classrooms

- Teacher/Trainer Online Journal Entries – participants are sent journal questions every other month about how their implementations are going and any barriers they may be experiencing.
- Pre- and Posttest Student Achievement Assessment – this instrument designed by the project staff and adapted for three levels (in the USA, grades K-4, 5–8, and 9–12, spanning primary and secondary grade levels) addresses student understanding of activities regarding science content such as Earth as a system, climate change and its impact on the local environment, and inquiry. Each item had a possible score of 3 points and a rubric was used to score each item. Interrater reliability (90 %) and content reliability were established for these items, and pre- and posttest data were analyzed using paired *t*-test.
- Teacher-Designed Assessments – teachers were asked during each workshop to collect additional evidence of student understanding related to implementation of the project. These often provided us with the best evidence of student understanding. They include the following:
  - Teacher-designed exams (pre- and posttest or just post-teaching a lesson).
  - Student journal entries – students wrote and/or drew about the topics they learned during the applicable lesson or unit.
  - Video tapes of students applying what they learned.
  - Photographs of students applying what they learned.
  - Interviews with students after applicable lessons/units.
  - Classroom observations during lessons/units.
  - Student individual, group, and class research projects applying what they learned in their local environment.
- Level of Implementation Analysis – these focused on the analysis of project impact by addressing the level to which each teacher implemented the program based on what strand/measurement protocol/activity(ies) of the project was incorporated into his or her classroom. They were also used formatively to make adjustments to the next PD workshop.

4 Results and Discussion

4.1 Professional Development Workshops

In the professional development workshop model that Seasons and Biomes developed, we used a model for student scientific investigation (Fig. 1) to integrate earth system science research into the workshop. A component of the scientific research model (observation, asking a research question, designing and conducting an investigation, data collection and analysis, communicating research results, etc.)

was chosen each day. It was highlighted in presentations, discussions, and activities in conjunction with the teaching and learning of earth science content and SAB and GLOBE scientific measurements in areas of investigation such as phenology, hydrology, atmosphere/weather, soils, and ice seasonality. A GLOBE Earth System Poster displaying monthly data of solar energy, surface temperature, cloud cover, precipitation, soil moisture, and vegetation with the accompanying learning activities not only served as a tool for exploring how the different components of the earth system work together and are interconnected but also provided a means of honing skills on data analysis – studying and interpreting data maps as well as helping integrate research into the PD workshop. We asked the teacher/trainer participants to read earth science and/or pedagogy content prior to the start of the workshop. We provided follow-up support such as research equipment, classroom visits, email and phone communications, and journal questions/responses regarding implementation in schools. The workshop consisted of inside and outside class activities including field trips. The best practices in teaching science were also incorporated and included a constructivist framework, cooperative learning, collaborative work, and inquiry student driven at various levels, accommodating different learning styles; allowing time for reflective thinking; integrating science with math, language, and art; and using authentic assessments. Scientists (including those early in their careers) have been involved in all the PD workshops as well as in all the global learning community projects, mentoring/collaborating with teachers and students.

Seasons and Biomes has conducted 33 regional, national, and international professional development (PD) multiday workshops, 21 as stand-alone events, and 12 through professional conferences or part of other workshops. International workshops were conducted in the USA as well as in other countries such as Australia, Belgium, Croatia, Estonia, Germany, Madagascar, Nigeria, South Africa, Tanzania, and Thailand. Seasons and Biomes has trained more than 1,400 teachers and trainers from 50 countries: Argentina, Australia, Bahrain , Belgium, Benin, Botswana, Cape Verde, Cameroon, Canada, Croatia, Czech Republic, Estonia, Ethiopia, Gabon, Germany, Ghana, Greenland (Denmark), Guinea, Hungary, India, Israel, Kenya, Latvia, Lebanon, Liechtenstein, Luxembourg, Macedonia, Madagascar, Malawi, Mali, Malta, Mauritania, Mongolia, Namibia, Netherlands, Nigeria, Norway, Panama, Paraguay, Peru, Rwanda, Senegal, South Africa, Spain, Switzerland, Tanzania, Thailand, Uganda, the UK, and the USA. Trainers and teachers have conducted at least 25 SAB PD workshops. More than 21,000 students are estimated to have been impacted through their teachers.

4.2 Teacher and Trainer Evaluation Results

4.2.1 Needs and Goals Survey (Pre-assessment)

Before each workshop, participants (teachers and trainers) were asked what skills and knowledge they hoped to gain from taking the PD workshop. This feedback was considered during our day-to-day planning for the workshop. The following table is an example of responses from workshops conducted in the USA.

Table 1 Teacher and trainer goals for attending Seasons and Biomes PD workshops in 2010 and 2011

Goal for attending	Number of participants selecting goal, May 2010	Number of participants selecting goal, June 2010	Number of participants selecting goal, August 2010	Number of participants selecting goal, June 2011	Totals for all workshops
Learn about GLOBE/GLOBE protocols/resources	10	4	6	4	24
STM content and ideas for teaching STM in my classroom (in hands-on manner)	5	6	2	4	17
Collect GLOBE data/add to GLOBE data set	2	2	2	6	12
More skills teaching science inquiry/help students ask research questions	2	4	1	4	11
Learn more about the environment, weather, climate, climate change	2	1	2	3	8
Professional connections (connect with others using GLOBE)	3	0	3	1	7
Better understand Earth as a system/Earth's systems	1	3	1	2	7
Motivate students	2	2	2	0	6
Authentic/relevant research projects with students	1	2	0	0	3
Place-based/community-based strategies	1	1	0	0	2
Learn more to be a better trainer	0	0	0	2	2

Table 1 indicates that GLOBE protocols and resources are a major draw for workshop participants as well as STM (science, technology, and math) content and teaching strategies. Using inquiry, forming professional connections, authentic opportunities to collect data, and student motivation were also important. These results are similar to those found in earlier years of the program (data not shown).

Teachers were also asked at the end of the workshops whether they met their goals and why. All the answers were in the affirmative and triangulated with their continued valuing of the topics in the table above. The following entries are representative of the responses:

> I am glad to be exposed to so many different protocols that I can pick and choose from. I also benefitted from the Student Research Model and different ideas about how to teach it/explain it to students. It was good to talk and share with different teachers about what they are doing. (Participant post-assessment, June 2010)

Table 2 Pre- and posttest teacher/trainer content/pedagogy results: 2008–2011 simple change scores and paired *t*-test results (*n* = number of workshop participants each year)

Year administered	Content or pedagogy item (stated briefly)	*n*	Simple change scores	*p*
2008	What is a biome?	37	+0.41	0.09
2008	Effect of climate on one biome	37	+0.28	0.10
2008	Effects of climate change on local ice	37	+0.33	0.08
2008	Changes in ice at your location	37	+0.53	0.02*
2008	What does "Earth as a system" mean?	37	+0.36	0.07
2008	Components of Earth as a system	37	+0.13	0.31
2008	Interconnectedness of components of Earth's systems	37	+0.43	0.15
2008	What causes seasons?	37	+0.54	0.01*
2008	Changes in seasonal events as an indicator and effect of climate change	37	+0.53	0.06
2008	Understanding of inquiry	37	+0.28	0.08
2009	What causes seasons?	12	+0.50	0.05*
2009	How climate change and seasons might be related in the context of Earth as a system	12	+0.59	0.03*
2010	What is inquiry?	36	+0.58	0.00*
2010	What are the components of Earth as a system and how are they interconnected?	36	+0.71	0.00*
2011	What is inquiry?	12	+0.31	0.00*
2011	What are the components of Earth as a system and how are they interconnected?	12	+1.08	0.00*

*Significance level $p \leq 0.05$

> This workshop has given me ways to allow my students to conduct authentic research. It has given me ideas for inquiry lessons. It has connected me with other teachers that I can collaborate with. (Participant post-assessment, June 2010)
>
> I have so many more ideas of great student-led research projects for my high school students. I also have more ideas on how to use an inquiry model (Participant Post-Assessment, May 2010)

4.2.2 Teachers/Trainers Content Pre- and Posttest Assessments

We adapted the content pre- and post-assessment items slightly depending on the content and pedagogy focus of the workshop (e.g., biomes, seasons, changes in their local environment, and Earth as a system, the importance of student research, inquiry).

Results shown in Table 2 suggest that teachers made significant progress in understanding earth system science content and pedagogy (inquiry) as a result of the PD workshops for years 2010–2011 and what causes seasons in 2008–2009. Results from 2008 helped us sharpen the focus of the workshops in succeeding years and develop a PD model to do this. Understanding of inquiry is needed to teach students the process of science and engage them in geoscience research investigations. This was accomplished through discussions and practicing how to do inquiry and going through the different steps in conducting a scientific investigation.

Table 3 Pre- and posttest Sun-Earth Survey results for two 2010 workshops: simple change scores and paired *t*-test results (n = number of participants)

Item number	Items	n	Simple change score	p
1	Shape of Earth's orbit	21	2.25	0.00*
2	Relative size of Earth, Moon, Sun	21	0.15	0.16
3	Why temperature is hotter in June than in December in the USA	21	1.0	0.00*

*Level of significance $p \leq 0.05$

Since an important part of Seasons and Biomes is seasons, we decided to check on participant understanding of what causes seasons using a different survey instrument. Lawrence Hall of Science *GEMS Sun-Earth Survey* (Gould et al. 2000) Each item was similarly assigned 3 points for a perfect answer, with possible points for each item ranging from 0 to 3.

Table 3 suggests that it is worthwhile to take time to teach what causes seasons as part of our Seasons and Biomes workshops. It is a fundamental understanding and the mean score on the pretest for item 1 was only 0.75 out of 3.00, indicating that the majority of teachers had misconceptions prior to the activity, but the posttests all scored 3.00 (perfect) on item 1. Item 2 pre- and posttest scores (2.70 and 2.85 not shown in table) were high, hence score change was not significant, suggesting that teachers had a good understanding of the relative size of planetary bodies. Item 3 presented six possibilities of why the USA is hotter in summer and change in score again was significant.

4.2.3 Most Beneficial PD Workshop Component Final Survey Results

When the workshop component scores (Table 4) were compared by ranking the highest score with a 1 rank, the second highest score a 2, and so on, consistently high scoring activities were mostly components from Classic GLOBE: phenology and atmosphere protocols and the Earth System Poster. An exception was the Chena River field trip where they did exploratory activities prior to learning and practicing the hydrology measurement protocols. However, even those activities that ranked the lowest such as alternative assessment and climate time series had mean scores of over 7 (on a scale of 1 least beneficial to 10 most beneficial), indicating that most of the activities or components of the workshops were found beneficial by the participants.

4.2.4 Program Implementation

Because the levels of classroom implementation can also be a measure of effectiveness and success of a project, we tracked how many teachers and trainers implemented each component of the project. Table 5 displays results in early 2009 as an example of what was being implemented in schools.

Table 4 Results of the most beneficial components survey for all workshops from 2008 to 2010 in the USA (n = number of participants who had the component in their workshop and rated it)

Component	n	Average ratings from participants	Rank
Phenology protocols	55	9.17	1
Chena River field trip	17	9.13	2
Atmosphere protocols	55	9.06	3
Observing/mapping your study site	28	8.97	4
Earth System Poster	55	8.86	5
GLOBE data entry	55	8.78	6
Ecology field trip and data entry with Dr. Jessie Cable	28	8.78	6
Hydrology protocols	45	8.72	7
Why do we have protocols	38	8.6	8
Ballaine Lake field trip	28	8.58	9
What causes seasons activity	55	8.37	10
Leaf inquiry to help generate research questions	55	8.31	11
Frost tube protocol with Dr. Kenji Yoshikawa	45	8.29	12
Student scientific investigation model	38	8.16	13
Ice seasonality protocols	45	8.01	14
Best teaching practice activity and discussion	28	7.80	15
Alternative assessment of student learning	28	7.68	16
Climate time series activity	28	7.35	17

Table 5 Teacher/trainer project implementation as of 3/30/2009 (n = 55, participants who reported)

Workshop/project components	Percent of participants implementing
Frost tube protocol	51
Entered data on the GLOBE website	47
Plant phenology protocols	36
Submitted evidence of student learning	29
Seasons and Biomes or ESS learning activities	26
Inquiry projects in the classroom	21
Thai mosquito protocols and learning activities	20
Atmosphere protocols and learning activities	19
Ice seasonality protocols and learning activities	11
Surface Temperature Protocol/Campaign	7
Online journaling/email reports	7
Invasive plant species protocol	5
GLOBE SAB Student Climate Research Campaign	3

The 2009 results (Table 5) indicate that workshop/project components most implemented were the frost tube protocol and data entry on the GLOBE website. The Student Climate Research Campaign was the least implemented but it had just started. The item on the mosquito protocols and learning activities were reported by teachers through their GLOBE scientist trainers/mentors in Thailand and the invasive plant species protocol by teachers through the GLOBE South Africa GLOBE Coordinator.

In 2007 and 2008, the following categories of data were submitted as evidence of implementation from the SAB teachers and trainers: data entry on the GLOBE website, data sent to Kenji Yoshikawa (depth of soil freezing), ice seasonality data sent to Kim Morris (Ice) and posted on a trainer website, student pre- and posttest assessments, teacher-designed assessments, green-up and green-down student inquiry reports (data analysis and investigations), online teacher journals, teacher emails, student journals, news articles, photos, student research projects presented at the South Africa GLOBE Learning Expedition (GLE), Spaceship Earth Project in Switzerland, and trainer and scientist Kevin Czajkowski's blog during the Surface Temperature Field Campaign he conducted.

In 2010 and 2011, similar categories of data were submitted by teachers and trainers as evidence not only of project implementation but also of gains in student understanding of earth system science and science process skills. Teacher and trainer emails also gave feedback on collaborations with teachers within a school or across schools as a result of the project. Markus Eugster, a SAB teacher who is also a trainer from Switzerland, initiated a project Seasons in My Biome (SIMB). SAB teachers and trainers (29 to date) from different countries who participate take monthly pictures on the same study site in their biome and post pictures as well as weather information, on the website http://www.seasonsandbiomes.net/110simb.html. They contribute to a photo collection and database for seasonality and phenology.

The Thai GLOBE trainers have been very busy implementing Seasons and Biomes since our workshops there in November 2008. There are now 21 student research projects in progress around the country. Two of the trainers and scientists, Drs. Krisanadej Jaroensutasinee and Mullica Jaroensutasinee, have worked with the SAB staff to develop a mosquito protocol to help teachers and students track the larva abundance of *Aedes* mosquitoes that are carriers of dengue fever. This protocol is accompanied by a series of learning activities that include an inquiry. The staff at the Institute for the Promotion of Science and Technology in Thailand have translated most of the SAB protocols and learning activities and conducted multiple Seasons and Biomes workshops. Two papers using student mosquito research have been accepted for publication, one to the Southeast Asian Journal of Tropical Medicine and Public Health (Wongkoon et al. 2013a), and the other to the Indian Journal of Medical Research (Wongkoon et al. 2013b).

According to the GLOBE Tanzania country coordinator and trainer Robert Lwikolela (2011, January 10, personal communication), Seasons and Biomes activities are integrated in science and geography subjects in primary schools and biology and geography in secondary schools in Tanzania. All the 70 teachers who were in the SAB workshop in Arusha strengthened their expertise in teaching primary and secondary learners. They are saying that the (SAB) training in Arusha had made them teach more efficiently. It also applies to the 250 teachers who were involved in the workshops in Dar es Salaam, Pwani, Tanga, Lindi, and Mtwara regions. These workshops involved training on Seasons and Biomes activities.

One of our teacher trainers from South Africa conducted a PD workshop hosted by the Dept. of Science and Technology in Johannesburg, South Africa, in late 2011, with teachers coming from all nine provinces of the country. The focus was on the GLOBE atmosphere, phenology, and land cover protocols and Earth System Poster, the SAB invasive plant species protocol, and the student scientific investigation model.

Barriers to Implementation

The most common barriers to implementation mentioned by the teachers and the trainers over the project years were the following: time (This seems to be a universal issue. It applies to preparation and contact time with students.); not enough training time in workshops (especially on data entry and use of the GLOBE website); data entry problems; problems with entering journals on Backpack, a web-based system (the project changed to a different system because of this problem); ice seasonality protocols too complicated for primary students; vandalism of equipment and study tree branches; stolen weather station; misunderstandings about expectations; weather problems; student lack of skills or gaps in skills; distance, encouraging teachers to submit project requirements and supporting them long distance; difficulties matching GLOBE strands to school curricula; lack of funding; lack of administrative support; and not having the necessary equipment.

4.3 Student Evaluation Results

4.3.1 Student Pre- and Post-content Assessment

Responses of students to open-ended questions before and after participation in Seasons and Biomes were rated using a rubric and statistically analyzed, and some results are shown below.

The results of the data analysis on student content assessment and science process (Table 6) indicate that the students made significant improvement on all test items. There were fewer responses (smaller n) for the last item on inquiry, because half of the students did not see this question on the back page.

Table 6 Pre- and posttest student assessment: 2008–2009 simple change scores and paired *t*-test results

Year administered	Item on science content and science process	*n*	Simple change score	*p*
2008–2009	What is a biome?	102	0.63	0.00*
2008–2009	Effects of climate change on local ice	102	0.65	0.00*
2008–2009	What does “Earth as a system” mean?	102	0.66	0.00*
2008–2009	Cause of seasons	102	0.61	0.00*
2008–2009	Understanding of inquiry	55	0.81	0.00*

*Level of significance $p \leq 0.05$

It has been difficult getting both the pre- and posttest student achievement assessments back from the teacher participants. Some of them remember to administer only the pretest, while others only the posttest. However, even though the change from pre- to postexposure to the program could not be measured, posttest responses can also show an in-depth understanding of key concepts even from primary (3rd and 5th grade level) students in this project. A few representative examples follow:

Item 1: Discuss how global change is affecting one biome:

Global change is affecting the tundra biome in many places in the world. Global warming is heating up the earth and making devastating marks in the tundra biomes. Take the Artic (sic) for example, Polar bears go out of hibernating in the spring when the ice is already starting to melt. Many have to feed their cubs and to do that the bears have to go farther where some places the ice is dangerously thin. If icebergs break off from the mainland with the bears still on them the bear might die. The iceberg would melt when it floats away into the warmer regions. The bear can swim, but not a long distance. Also global warming causes perma-frost to melt in the frozen tundra around the world….that has been on the tundra for millions of years. This would ruin the biome as well as the ecosystems that are in it. Also there would be an exceeding amount of water in the world. This might ruin other biomes, which are hundreds of miles away, too (5th grade student post assessment 3/08)

Item 2: Explain your understanding of science inquiry (e.g., what it is and why it is important) and give an example of what it looks like in your classroom:

My understanding of inquiry would be asking questions and having a hypothesis and doing an experiment to find out the answer. Example: slope stability.
(This was followed by an excellent diagram of their experiment.) (3rd grade student post assessment 3/08)

Item 3: Discuss your ideas about what the term "Earth as a System" means. Be as specific as possible and give examples.

My ideas about the term "Earth as a System" include that I think that the Earth is just like any other kind of "system". I think that in that way if one "system" of the Earth is somehow affected, then a lot of the systems could get affected. Like if precipitation was affected so that rain was a little less frequent around rain forests, then vegetation in the rainforest would change. The vegetation might change because the plants in the rainforest are used to much rain. So if they don't get as much, some plants might die, releasing nitrates and CO2. Also, the cloud cover, temperature, and soil moisture systems might change some too. And other systems work like that, too. Like with maybe the circula-tory system in the human body. If the heart pumps less blood to maybe parts of your hand, your hands might lose some amounts of movements because all parts of your body use oxygen to work. So if you can't move your hands as much, you might not be able to pick things up like food, so you might not be able to get it to the digestive system. And if you don't use your hands much,

Table 7 Teacher-designed pre- and posttest student content assessment: 2009–2010 simple change scores and paired *t*-test results

Year	Content item	*n*	Simple change score	*p*
2009	Discuss your ideas about what you think budburst is.	13	+0.04	0.37
2009	Discuss what your ideas are of the seasonal factors that affect the timing of budburst.	13	+0.55	0.02*
2009	Why do you think those seasonal factors affect the timing of budburst?	13	+0.48	0.07
2009	What do you think are the developmental stages before and after budburst?	13	+0.14	0.17
2010	Discuss your ideas of what you think budburst is.	11	+0.37	0.00*
2010	Discuss what your ideas of the seasonal factors that affect the timing of budburst.	11	+0.50	0.00*
2010	Why do you think those seasonal factors affect the timing of budburst?	11	+0.59	0.00*
2010	What do you think are the developmental stages before and after budburst?	11	+0.36	0.00*

*Level of significance $p \leq 0.05$

you might lose muscle mass. So all the systems in the circulatory system work together. And so do the Earth systems. So the Earth is just like other systems. Another idea I have about "Earth as a System" is that all the system make up something…. All systems add up to something more. And the Earth is no exception (5th grade student post-assessment 3/08)

4.3.2 Teacher-Designed Student Assessments

A number of teachers have submitted some excellent teacher-designed assessments along with the SAB pre- and post-content assessment. Below is a representative example.

In this teacher-designed assessment for students before and after they started doing the phenology investigation using the GLOBE budburst protocol, all posttest scores were higher than the pretest scores with only one item score change being significant (item on seasonal factors that affect budburst) in 2009 (Table 7). However, in 2010, all score changes between pre-and posttest for all items in 2010 were significant. This suggests that the students in the class of 2010 increased their knowledge of budburst and the seasonal factors that affect the timing of budburst that is used as an indicator for the beginning of the plant growing season.

4.3.3 Other Evidence of Student Learning

Teachers are really beginning to understand what can count as evidence of student learning. The quality of teacher-designed assessments and the evidence of understanding they have provided have increased tremendously since the project began. These included student journal entries; paper and pencil test (e.g., multiple choice, short answer, essay, graphing); budburst journals; budburst pre-and post-assessments; earth system science posttests and scores; what causes seasons post-assessment; digital photos; GLOBE data sheets (phenology and atmosphere); teacher-designed data sheets; student research papers and presentations; student research inquiries related to green-up, green-down, budburst, etc.; data sheets from student inquiries; student work posted on teacher, trainer, and school websites, blogs, or wikis; class discussions (observed and reported by teachers); graphs; student-designed maps of the study site; student-designed concept maps of climate change clearly showing connections made; open response assessments; student stories that include the key concepts studied; research presentations for science conferences such as the GLOBE Learning Expedition; dictated verbal responses and drawings from first graders; and postings on teacher, trainer, and school websites.

The following teacher journal entries support the findings of the pre- and post-content assessments and teacher-designed assessments for students, on student understanding of earth system science and the science process, and are representative of many that we received from the teachers and trainers:

> They (the students) have learned so much about climate change, global environmental issues, politics involving climate change, It's made them much more aware of the earth's limitations, human impact and cultural traditions that have changed. It has made them understand the importance of long-term data collection and they are proud to be helping in such an activity (Teacher email survey 3/09)
>
> It is reinforcing the inquiry-based approach to science teaching and exposes them to a global perspective (Trainer email survey 3/2009)
>
> All of my students are becoming much more aware of how the entire "earth system" is interconnected. They are excited to know they are part of an international network of students contributing data. (Teacher email survey 3/2009)
>
> One of the most global learnings that I think my students have is that when they take readings in GLOBE and notice changes, especially out of the ordinary data, it doesn't illustrate climate change. It is only when we see trends over long periods of time that we can draw conclusions. But our data is very valuable because it fills a tiny piece of the climate puzzle for scientists to see trends. I think GLOBE is very helpful in letting students realize the difference between weather and climate. (Teacher Journal 11/2011)
>
> By collecting and submitting data for SAB, students' work has meaning. Students get to think and act like scientists. I believe these lessons will be long remembered. A class can't get much better than this! (Teacher email survey 3/2009)

4.3.4 Student Research Investigations and Presentations

The teachers and trainers reported to us about students who have conducted earth/environmental science investigations. Some research projects were done as a class, by a group of students, or by individuals. In 2008, two projects of students of SAB teachers were chosen to be presented at the GLOBE Learning Expedition, an international conference held in South Africa. One project was on the effect of wildfire on plant regrowth and vegetation phenology using GLOBE protocols and traditional ecological knowledge, conducted by Alaska Native students from Shageluk, Alaska. The second was a collaborative SAB budburst phenology study of students from the Model Secondary School for the Deaf in Washington, DC, and students from Indiana Secondary School for the Deaf. Another study presented by the Washington, DC, students won first place at the US Science Fair for the Deaf. A study on the effect of a power plant on river freeze-up was awarded fourth place at the Alaska Statewide High School Science Symposium.

In Thailand, at the Climate Change Education and Earth System Science Conference held in Jan 2010, Thai GLOBE teachers and their students presented their research findings on ten research projects on how mosquito larva abundance and distribution are related to local atmospheric conditions. There are currently more than 21 ongoing student earth system science projects on mosquitoes and vegetation phenology in Thailand.

In Ohio, USA, at a virtual conference, 35 primary and secondary student teams presented their SAB research projects, and at a face-to-face conference, 36 precollege student teams presented their projects. These conferences were organized by a SAB trainer and scientist in 2009 who has held similar student conferences and teacher conferences, in the following years. In 2011 and 2012, a student team from Ohio, USA, participated in the White House Science Fair.

In Alaska, USA, there are many ongoing classroom earth science inquiries/investigations on soils, phenology, depth of soil freezing, arctic bird migration, and land cover change. For example, since 2009, students at Mat-Su Career & Tech Ed High School in Alaska have been immersed in a field-based research project to develop baseline data on the emergence of tree buds as a way to monitor climate change. They have shared their data with the State of Alaska Forestry Division, and the Wasilla Soil and Water Conservation District, which was used to help a federal agency research team decide when to start their survey of bald eagles. Since 2007 the numbers of schools engaged in monitoring soil temperatures, as well as the depth and timing of soil freezing, have increased to almost 200 in Alaska, plus several other schools in Illinois and Ohio, USA; in Uzwil, Switzerland; and in Canada.

Seasons and Biomes students are among the 1.5 million students who have contributed 22 million measurement data to GLOBE (http://www.globe.gov) and have also contributed to SAB data that are archived elsewhere (e.g., http://www.uaf.edu/permafrost). Scientists have used GLOBE data in their research (Wongkoon et al. 2013; Yoshikawa et al. 2013; Gazal et al. 2008; Robin et al. 2005, 2007; Ault et al. 2006; White et al. 2000). Students have also conducted their own investigations, analyzed the data, written papers, and shared their findings at statewide, nationwide, and international conferences. GLOBE Alumni and teachers have also given presentations on their work with SAB students at the Oslo 2010 IPY Conference and other international as well as national conferences.

4.4 *Student Engagement in Geoscience Through Global Learning Community Projects*

4.4.1 IPY Pole-to-Pole Videoconferences

The first one in 2007 involved students from Effie Kokrine School, Pearl Creek Elementary School, and Moosewood Farm Home School in Fairbanks and Tri-Valley School in Healy, Alaska (AK), USA, and students from Ushuaia, Argentina. The second videoconference in 2008 engaged students from Randy Smith Middle School and Moosewood Farm Home School in Fairbanks, AK; Innoko River School in Shageluk, AK; Wasilla High School in Wasilla, AK; and Ushuaia, Argentina. Students discussed environmental changes happening in their locale and talked with and listened to arctic, subarctic, and antarctic scientists in Alaska; Boulder, Colorado; Washington, DC; Buenos Aires; and Ushuaia about climate change and planned some studies. The videoconferences were followed by web chats and web forums, to allow students from other parts of the world to communicate with scientists and ask questions about climate change. These activities inspired student research investigations and collaborations across schools.

4.4.2 Intercontinental Science and Literacy Education Projects

Seasons and Biomes collaborated with another IPY project, *Ice e-Mystery*: Global Student Polar e-Books, in Australia; and a project titled Ice e-Mysteries Polar e-Books: An Innovative Approach to Science and Literacy Education, in the USA. We conducted professional development workshops in the USA and Australia for teachers on Seasons and Biomes scientific measurement protocols, polar science, collaboration/communication tools, and art. Students in 12 paired classrooms from Alaska, USA, and Tasmania, Australia, collaboratively wrote and illustrated 12 polar books on fictional stories but with authentic polar science. These books are published on the website http://iem.tmag.tas.gov.au/. Collaborations on science investigations between schools continue as do friendships made across the continents.

4.4.3 GLOBE Alumni

We provided training and support to GLOBE Alumni, former GLOBE students who have graduated from tertiary school but are still interested in and excited about GLOBE and helping teachers implement earth science investigations in their classrooms. These GLOBE Alumni who were chosen from the different world regions were also trained as GLOBE IPY Ambassadors in our SAB PD workshops. GLOBE Alumni have also facilitated web-based student-driven discussion forums about weather, climate, biomes, and environmental change, among schools in different countries through GLOBE School Pals (GS-Pals). Recently, Matt Fenzel, the GLOBE North American Alumni Representative, and Juan Diego Calvo-Perez Rodo, the GLOBE Latin American Alumni Representative, facilitated a GS-Pals event entitled “An Exploration of the Seasonal Indicators in My Local Environment”. The project promoted the exchange of information on migratory birds, from the subarctic polar zone of Alaska in the USA to the tropical zone of Peru, allowing students to learn how migration patterns correlate to temperature and food availability and to explore the diversity of cultures between countries.

4.4.4 Mt. Kilimanjaro Expedition

Seasons and Biomes collaborated with GLOBE Africa on expeditions to Mt. Kilimanjaro where scientists, teachers, and students (in 2010, from Alaska, USA, and Tanzania) who climbed the mountain were accompanied virtually by hundreds of students all over the world (in 2010 students from more than 80 countries joined). As the expedition members experienced different ecozones/biomes on their climb to the Mt. Kilimanjaro summit, the other students following the expedition virtually posted the biomes in which their schools were located and asked questions through the expedition website. As trekkers took scientific measurements during the climb on Mt. Kilimanjaro, the virtual climbers were also encouraged to take measurements such as air and soil temperature and precipitation at their schools.

5 Conclusions

A multiplier effect has resulted from the Seasons and Biomes PD workshops that were conducted. Seasons and Biomes trained trainers (educators and scientists) and some teachers have conducted their own workshops resulting in almost as many as the SAB staff have conducted. This project has contributed to the professional development of teachers and trainers from 50 countries as well as those of early career scientists who gained some experience working with teachers while sharing their expertise during the SAB workshops. Seasons and Biomes students are among the 1.5 million students who have contributed 22 million measurements to the GLOBE database; SAB students have also collected other data that they contributed to other data archives. Students have also conducted their own earth system science investigations, analyzed the data, and shared their findings at statewide, national, and international conferences.

Students learn and understand earth system science through their teachers who have gone through Seasons and Biomes PD workshops as well as through the global learning community projects such as the Pole-to-Pole Videoconferences, the Ice e-Mystery Polar e-Books, the Mt. Kilimanjaro expedition, and the global discussions and collaborations facilitated by the GLOBE Alumni. Evaluation results, other evidence of student learning provided by teachers, and numerous student investigations suggest high SAB implementation and increased student understanding and skills in geosciences. There has been an increasing demand from GLOBE countries to use the Seasons and Biomes professional development model that integrates earth system science concepts, model for student research investigation, and best teaching practices for relevant inquiry- and place-based geosciences projects. Students are contributing to spatial and temporal distribution of baseline data needed for long-term studies such as climate change and its impacts. This project is contributing critically needed science measurements that may be used to validate satellite data and/or used in research on regional climate change, prevention and management of diseases, and understanding of the water and carbon cycles.

Overview

Background and Motivation

– The Monitoring Seasons Through Global Learning Communities project, also known as Seasons and Biomes, is an International Polar Year (IPY) project that integrates earth system science and environmental research in the teaching and learning of science in primary and secondary schools.
– Seasons and Biomes is an inquiry- and project- based initiative that monitors seasons and seasonal indicators' interannual variability to increase understanding of Earth as a system, learn science as process and inquiry, contribute to earth system science and climate change studies, and participate in the fourth IPY and beyond.

Innovation and Findings

– We developed for teachers and trainers a professional development (PD) workshop model that used a student scientific investigation model to integrate earth system science content, SAB and GLOBE measurement protocols, and best teaching practices such as inquiry, constructivist framework, and alternative assessments. Opportunities for collaborations with scientists and local experts and long-term support for classroom implementation were provided. Evidence for SAB program's effectiveness has been presented.
– Students learn and understand earth system science by engaging in geoscience research with guidance from their teachers, scientists, and local experts and through global learning community projects such as the IPY Pole-to-Pole Videoconferences, the IPY Ice e-Mystery Polar e-Book project, the Mt. Kilimanjaro expedition, and the intercountry discussion forums and collaborations facilitated by the GLOBE Alumni.
– Whole classes, small groups, and individual students have presented the findings of their geoscience investigations at statewide, national, and international science conferences, and have contributed to long-term earth system science studies.

(continued)

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Implications for Wider Practice

- More than 1,400 teachers and trainers in 50 countries have participated in Seasons and Biomes PD workshops that focus on deepening understanding of Earth as a system and engaging their students in geoscience research as a way of teaching science content and process at many levels all over the world.
- In addition to the 33 Seasons and Biomes PD workshops, educators and scientists who learned from us have conducted their own workshops (25), thus informing a wider audience and increasing the reach to almost 21,000 students, with potential to reach even higher numbers of teachers and students.
- Engaging precollege students in geosciences research contributes to student understanding of Earth as a system and contributes spatial and temporal data needed for studying the Earth.

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Bridging Scientific Research and Science Education in High Schools Through Authentic and Simulated Science Experiences

Lucette Barber

1 Introduction

The year was 2002, and Canadian scientists working in the Arctic were feeling a renewed optimism as a result of a growing political willingness to support and fund Arctic climate change research. At the lead of this optimism was a group of Canadian researchers proposing to purchase and retrofit an icebreaker from the Canadian Coast Guard fleet, into a state-of-the-art research vessel. This icebreaker would become the platform for Arctic ecosystem studies under the banners of the Canadian Arctic Shelf Exchange Study (CASES), ArcticNet and International Polar Year (IPY) projects such as the Circumpolar Flaw Lead (CFL) system study.

The year is now 2011 and these ambitious multidisciplinary programmes have contributed to the transformation of Arctic research both in Canada and internationally, by involving scientists from academic and government facilities around the world, in collaborative interdisciplinary research aimed at a better understanding of the complexities and changes of the Arctic marine ecosystem and the impacts of those changes on northern peoples.

This evolution in research is occurring simultaneously with a global concern about climate change that is generating greater interest in environmental issues and a growing demand for scientists to become more engaged with the public and decision-makers. This growing demand for scientific outreach especially in the area of environmental research and education is in response to a number of influences including, but not limited to:

- An international recognition of the important role of education in addressing global environmental issues (UNESCO 1977, 1992, 1997; WCED 1987) evident by the declaration of the United Nations Decade of Education for Sustainable Development (2005–2014)

L. Barber (✉)
Centre for Earth Observation Science, University of Manitoba, Winnipeg, Canada
e-mail: Lucette.Barber@umanitoba.ca

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- Interest by politicians and policymakers in creating a knowledge economy/society (Gough 2002) or, as Chapman and Pearce (2001) suggest, a 'knowledge culture' that will be able to address complex environmental problems
- Reports from the International Council for Science (2011) and the European Commission (2007) identifying an international decline in the enrolment of students in key science studies and an urgent need to promote and increase interest in science through inquiry-based education
- Reforms in science education that include a greater focus on scientific inquiry and making science 'real' for learners
- Research-funding agencies requiring scientists to demonstrate how they plan to communicate their science to the public and inspire the next generation of scientists

All of these factors recognise the role that educators and scientists can play in increasing scientific and environmental literacy and inspiring young people to consider future careers in science, engineering, technology and research (Avery et al. 2003; Kurdziel and Libarkin 2002; Trautmann and MaKinster 2005). It might be argued that scientists today have a civic responsibility to inform and interact with the public especially if their research relates to an issue, such as climate change, which is broader than a scientific matter (Backstrand 2003; Bralower et al. 2008). This rationale and demand for scientific outreach leads to the question: 'How do we *effectively* link scientists with education?'

In 2002, our answer to this question was to develop and pilot the Schools on Board programme (SonB). The aim of the programme was to create field experiences for high school students and teachers in Arctic climate change research. The programme is now a national outreach programme of ArcticNet, a Canadian Networks of Centres of Excellence (NCE) focused on Arctic climate change research involving scientists and researchers from universities and government agencies across Canada and the world. The SonB programme operates out of the University of Manitoba (Winnipeg, Canada) and is currently staffed by a full-time programme coordinator and a programme manager. The programme was designed and presented to scientists in 2002, introduced to schools in 2003 and piloted in 2004 as an outreach programme of the Canadian Arctic Shelf Exchange Study (CASES), the first project to deploy the *CCGS Amundsen* as a dedicated research icebreaker. The successes of the first field programme led to a continued support from the scientific community and the Canadian Coast Guard Service (CCGS) to plan future field programmes and broaden the programme to include the Arctic Climate Change Youth Forum (ACCYF) and Arctic Science Days.

This chapter focuses on an experiential approach to bridging research and education through authentic and simulated science experiences. Authentic science experiences refer to experiences in a genuine or real research situation, working with experts in a setting where scientific investigation is conducted such as a laboratory or field site, conducting one's own research or contributing to an existing project. Simulated science experiences refer to experiences that include some or all aspects of a scientific investigation. These experiences can occur in a classroom, school laboratory, research facility or field site and are led by a more knowledgeable

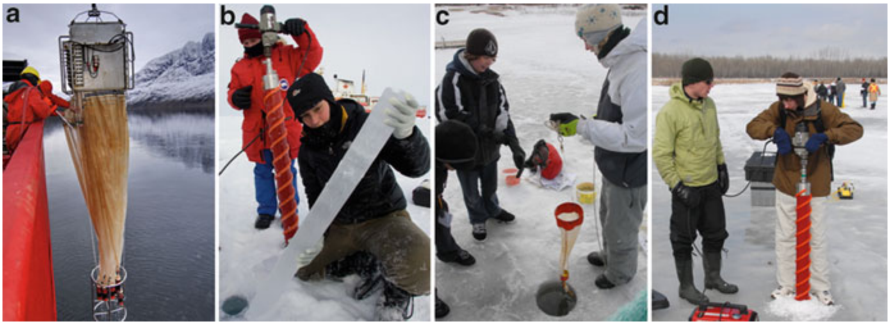

Fig. 1 Authentic science experiences from the field programme (a/b) easily simulated in an Arctic Science Day (c/d) at FortWhyte Alive, outdoor education centre (Winnipeg, Canada) (Photo credits: a – ArcticNet; b – Doug Barber; c – Schools on Board; d – Schools on Board)

person, which can be a science teacher, a knowledgeable student, an expert or scientist (Fig. 1).

The SonB programme focuses on outreach activities between scientists and schools (students and teachers), often referred to in the literature as 'research partnerships'. These partnerships range from email correspondence between scientists and students in a classroom to scientists bringing students and teachers into their labs or field sites to experience research first-hand. These experiential programmes can increase understanding of the scientific process by integrating research and education in a very hands-on/minds-on approach (Harnik and Ross 2003). An experiential approach to learning blends direct experiences with reflection (critical thought, discussion and self-reflection), abstract conceptualisation (forming conclusions, interpretations) and active experimentation (application of new knowledge to new cycle of learning, application of technology) placing the learner directly in touch with what is being studied and placing the focus on *how* something is being learned rather than on *what* is being learned (Kolb 1984).

Scientists are in the unique position of being able to make science real for learners (students and teachers). In authentic and simulated research experiences, learning at the 'elbows of scientists' allows students to experience the excitement of science and introduces them to the culture of research, which includes the knowledge, skills, language, traditions, behaviour codes, values, social interactions and passions of the scientific community (Barab and Hay 2001; Bleicher 1996). These science or research experiences can create 'aha' moments that provide an added emotional layer that heightens learning (Elster 2006) and cannot be taught from a textbook. It is this unique and powerful learning experience that continues to provide motivation and strong rationale for providing opportunities for scientists and schools to come together in complementary goals of communicating science and promoting science education.

2 Programme Description

2.1 Goals and Objectives

All components of the Schools on Board programme share the following overarching goals:

- To promote and expand Arctic sciences in schools across the country
- To link schools to Canada's Arctic research community
- To inspire the next generation of Arctic scientists, managers and policymakers
- To increase public awareness of the Canadian Arctic and its inhabitants
- To showcase major Canadian research initiatives in the Arctic

2.2 Programme Components

The initial concept plan for the programme included three components: a network, a field programme and a student forum. These three components allowed us to extend our outreach beyond the few students, teachers, schools and scientists participating in the field programmes. The success of the youth forums stimulated the development and promotion of the Arctic Science Day. These 1-day events feature scientists simulating Arctic fieldwork in a number of different environments (Fig. 2).

Schools on Board Network: The network identifies educators (formal and informal), scientists and outreach agencies interested in Arctic sciences. It was created of necessity as an inexpensive and reliable means to disseminate information, with the intention that it would become the main means of communication for sharing information on educational materials and resources, field opportunities and new initiatives. The network began with 10 educators from the participating schools, the advisory committee and the estimated 200 scientists in the CASES network. In 2011, the network consisted of 225 educators; more than 400 ArcticNet, CASES and IPY-CFL scientists; 175 agencies; 65 media representatives; 70 international contacts; and 120 SonB alumni (teachers and students who have participated in a field programme or organised a youth forum).

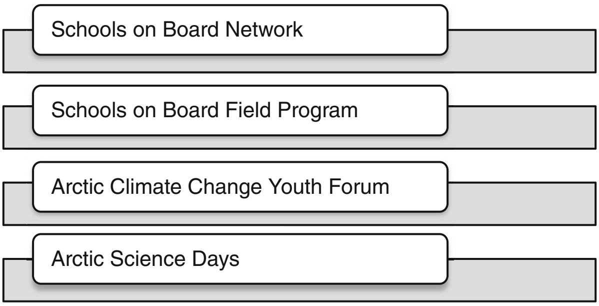

Fig. 2 The four components of the Schools on Board programme

Schools on Board Field Programme: The field programme provides unique opportunities for students and teachers to join scientists in the Canadian High Arctic on board a research icebreaker, where they become completely integrated into life on the ship and in the research activities of the science teams. The onboard programme is planned by a coordinator in collaboration with onboard scientists and is delivered by participating scientists in the field. It includes a blend of interactive lectures, lab activities and fieldwork in the science disciplines represented on the ship. This component is described in greater detail in the next section.

Arctic Climate Change Youth Forum: This 1-day forum is co-hosted with a high school and is planned in conjunction with a major national or international science conference, attracting scientists attending the conference to participate in the science programme of the forum. This is a collaborative initiative that requires full school participation and support from school administrators. The event is planned entirely by a student committee that includes two or three teachers as advisors. It is a major initiative that requires 6–7 months of planning meetings and dedicated space to accommodate 250–400 students and teachers and 30–35 participating scientists. The morning is dedicated to the science of Arctic climate change research (interactive presentations and 'hands-on' simulated research activities with scientists). The theme of the afternoon is the 'role of science in policy- and decision-making. These broad guidelines ensure that each forum follows a model that includes both the science and the issues related to climate change. It allows each student organising committee to determine how their forum will engage the youth in both the science and issues of the day.

Arctic Science Days: This 1-day event has evolved from the ACCYF. The focus is on hands-on science of Arctic climate change research. The model for the day is a series of stations planned and delivered by scientists. Scientists explain their field of study and simulate fieldwork activities conducted in the field. In this collaboration scientists plan and deliver the science sessions, and educators prepare the students with background information, select and transport student to the designated location (if outside of their school) and assist students in making the connections between science in the field and science in the classroom. These science days are easily adapted to meet the needs of smaller science teams or individual schools who have more limited resources. This model for outreach is being promoted to scientists and graduate students through the ArcticNet Student Association network and has been implemented successfully by teams of as many as 25 scientists to smaller groups led by two or three scientists.

2.3 Target Group and Scope

The following factors were considered when identifying our target group:

- The geographical scope of the scientific project (ArcticNet)
- The level of scientific knowledge required to appreciate and anchor the experience
- The remoteness of the field programme
- Programme logistics and risk management issues

Fig. 3 Group photos for the 2006 and 2009 field programs. Each student and teacher represents a school or programme that has successfully competed for spaces in the program (Photo credits: Schools on Board)

The result is a national programme, reflecting the national scope of the research project, targeting high school students (16–18 years old) and teachers from across Canada. A typical field programme involves nine students, two teachers and a programme leader (Fig. 3).

As the name suggests, ‘Schools on Board’ identifies schools as the primary targets for all initiatives, especially the field programme. Since the space on the ship is limited to only 12 participants, the decision to accept applications from schools rather than individuals establishes a collaborative relationship between SonB and participating schools. This relationship of shared responsibilities and shared vested interests allows the creation of significant experiences for the individuals selected while maximising the outreach potential of the programme to include the entire school and its community. A unique feature of the field programme is the School Application that includes a detailed outreach plan describing how the school plans to integrate Arctic sciences into their programmes and how the experiences of their student or teacher will be shared more broadly within the school or division.

The target group for the ACCYF is a high school audience. Each forum in promoted nationally through the SonB network. Schools are invited to register 5–10 students and teachers. This limited registration per school ensures a greater number of schools participating in the event. The three youth forums planned to date average 300 students and teachers from 25 to 30 schools. The Arctic Science Days are planned for diverse age groups. The level of science delivered is determined through discussions between the participating scientist(s) and the educator(s) to meet the level of students attending. This event has been planned successfully for high school students, middle years and early years.

3 Programme Planning Framework

The experiential approach adopted for all SonB programme initiatives is aimed at teaching ‘about’ science and climate change ‘in’ an authentic or simulated Arctic research environment and providing a powerful platform for promoting positive attitudes and behaviours ‘for’ science education and environmental stewardship.

Table 1 Programme characteristics related to educating about, in and for science and the environment following Barber (2009)

Educating 'about' content	Educating 'in' setting	Educating 'for' context
Scientific knowledge	Situated learning	Discussion of issues
Ecological knowledge	Place-based learning	Values and attitudes
Technology	Authentic science setting	Perceptions
Nature of science	In nature	Critical thinking
Multidisciplinary	Experiential	Critical reflection
Interdisciplinary	Learning from experts	Problem-solving
Cross-curricular	Places of inquiry	Decision-making
Multiple perspectives	Connection through direct experience	Action and change
Knowledge of issues		

This section describes the educating 'about', 'in' and 'for' framework that guides the planning of each field programme and the development of other programme initiatives such as the Arctic Climate Change Youth Forum and Arctic Science Days.

In 2008 the Schools on Board programme was the subject of a case study that looked at the documented successes of the programme and asked how and why the programme is working (Barber 2009). Two of the research objectives of this study were to (1) review literature on environmental education, science education and scientific outreach to gain a better understanding of the criteria for quality environmental science education programmes and (2) apply these criteria to evaluate the SonB programme and provide theoretical grounding to our understanding of why the programme is successfully creating positive experiences for participating students, teachers and scientists. This qualitative research project followed the action research design and sequence described by Stringer (2004) and utilised the case study method described in Patton (1990) and Yin (2003).

The study revealed enough common ground in the literature of environmental education, science education and scientific outreach to develop criteria or guidelines for developing quality environmental science education (ESE) programmes. These criteria (Table 1) suggest that content, setting and context should be considered in planning and delivering programmes.

Each criterion is necessary to ensure a quality ESE programme; however, the focus on each will vary with every initiative. The key to quality programming is to ensure that all three are considered and planned into the programme to some degree. The following section describes each criterion in detail and how it is implemented in Schools on Board programme.

3.1 Criterion #1: Educating About the Environment and Science

This criterion relates primarily to the content or knowledge of a programme. This includes essential, credible and reliable ecological and scientific knowledge that is relevant to specific concepts, environmental issues and technology – its impacts on society and the environment and its role in the scientific process. Content should be grounded in real life and presented within the broader social context, for example, connected to global environmental issues such as climate change and sustainability. The philosophy and nature of science is fundamental to educating 'about' science.

Education 'about' the environment and science should be age appropriate and relate to concepts that are already known or familiar so that new knowledge can be constructed or anchored onto previous knowledge. It should be multidisciplinary or interdisciplinary in nature, to reflect the complex and holistic or systemic perspective of science and the environment. Whenever possible, educating 'about' science and the environment should include multiple points of view or alternative 'ways of knowing' such as traditional ecological knowledge (TEK) and should consider, whenever possible, cross-curricular links to other subjects such as the arts, mathematics, political sciences, social studies and health.

3.1.1 Implementation in Schools on Board

The field programme acknowledges the critical role of prior knowledge for creating new knowledge. The criteria for student selection include Grade 10 Science as a minimum requirement. The programme also requires that school representatives (administrators and/or teachers) select students based on their knowledge of the student's abilities and knowledge. Background materials and resources are provided to participants prior to departure. Collaboration with educators provides insight to curricular links to science, geography, environmental education, learning for sustainable futures, climate change and Experiential Sciences/Arctic Marine Science Curriculum developed in Northern Canada (Campbell et al. 2009). The specific science content for each programme is determined by participating scientists and their area of research in Arctic sciences.

Scientific and Ecological Knowledge

The content of the programme, whether it is the field programme, youth forum or science day, focuses on scientific investigation of the Arctic marine ecosystem. An emphasis is placed on demonstrating the multidisciplinary and interdisciplinary nature of the research programme, the interconnectedness of the science teams around the unifying theme of climate change. Knowledge of the environmental and social issues related to climate change is an essential component of the programme (Fig. 4).

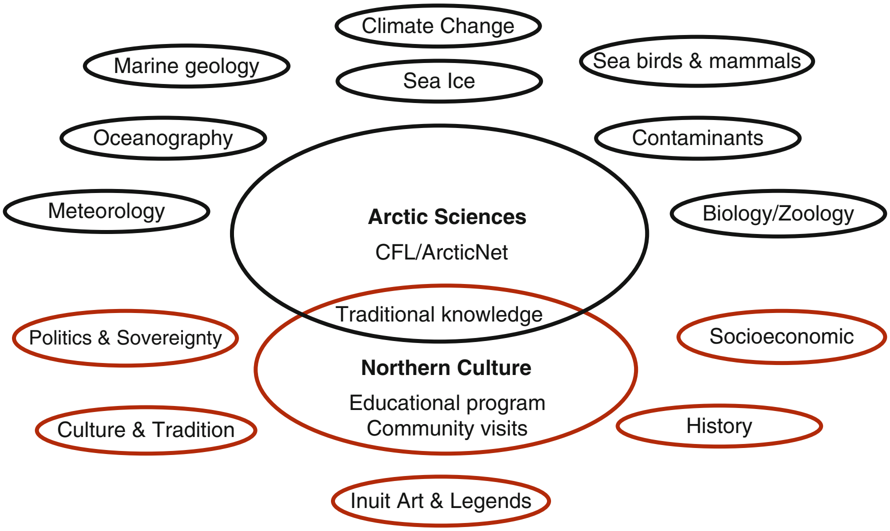

Fig. 4 Educating 'about' Arctic climate change research in SonB programs involves a multidisciplinary scientific perspective, northern perspective and the intersection of both where traditional knowledge and science are integrated and shared

Multiple Perspectives

In addition to multiple perspectives of the scientists, the programme includes traditional ecological knowledge (TEK) and Inuit observations of climate change. Face-to-face interactions with northern community leaders, the elders and local high school students in the North, as well as interactions with the Inuit wildlife monitors on the ship, provide participants with another 'way of knowing' to complement the scientific focus of the programme. This integration occurs on many levels through face-to-face interactions with the elders, northern researchers, community leaders and indigenous youth, as depicted in Fig. 5. A student in the field programme learns about sea ice and hunting from a wildlife monitor during a field programme, an elder shares his knowledge with students on board the CCGS Amundsen and an Inuit youth from Nunatsiavut (Labrador, Canada) is invited as a keynote speaker to the 2010 Arctic Climate Change Youth Forum in Winnipeg.

The integration of indigenous knowledge provides a holistic perspective of scientific research in the Arctic and makes science more culturally relevant to indigenous students, teachers and community members (Cajete 1999). It also promotes scientific thinking that allows for the existence of alternative interpretations, explanations and solutions to complex problems (Corsiglia and Snively 2001).

Fig. 5 Integrating Inuit and scientific knowledge of climate change in the Arctic through the interaction with the Inuit elders, leaders and youth during the field programs and youth forums

Fig. 6 Students build thermocouples in teams and then work with scientists to properly install the instruments in the snow (Photo credit: Schools on Board)

Technology

Authentic and simulated science experiences introduce participants to the diversity of research tools and techniques used by science teams working at the different scales of investigation (i.e. microscopy to satellite imagery). Technology plays a significant role in all stages of scientific investigation from collection of data to analysis and interpretation and, finally, to the communication of results. Technology is presented as an essential part of scientific inquiry. The field programme includes a design activity that challenges participants to design and construct an instrument from basic materials that simulates the function of a more sophisticated instrument used by scientists on the ship. Students have built 'pyranometers' to measure solar energy and temperature probes (Fig. 6) to measure temperature in snow at varying depths.

Cross-Curricular

Cross-curricular sessions are encouraged whenever possible. These sessions have included Inuit art and legends, music and science, Arctic literature, Arctic exploration and Arctic sovereignty and governance. It is common for schools applying to send a student or teacher on the field programme to demonstrate how Arctic sciences and Arctic themes will be integrated in all their programmes during their involvement with the programme.

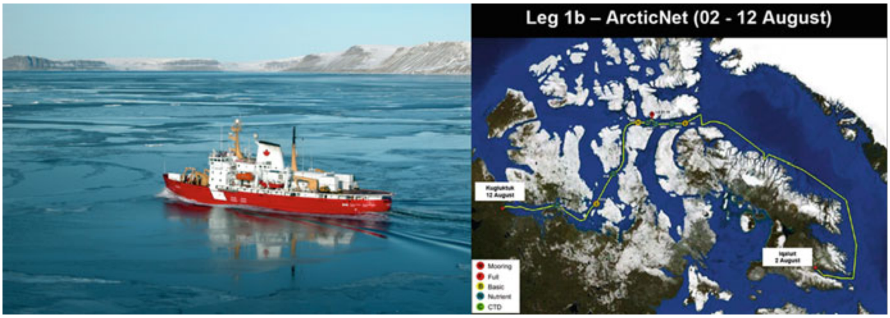

Fig. 7 Photo of the CCGS Amundsen and a map outlining the route of the field program onboard Leg 1b of the 2010 ArcticNet scientific expedition that departed on August 2nd from Iqaluit NU, travelled through the Northwest Passage, and arrived in Kugluktuk on August 12, 2010 (Credit: ArcticNet)

3.2 Criterion #2: Educating in the Environment and Science

This criterion relates primarily to the setting or location of a programme and suggests that 'how' we experience learning is affected by the places and spaces in which we learn. This criterion recognises the environment as a setting for learning, not just a topic to cover in a classroom, and recognises authentic science settings such as laboratories (school based and off site) and field sites, as places of scientific inquiry. Situated learning theory states that learning is embedded within activity, context and culture and that knowledge should be presented in settings and situation that normally involve that knowledge (Lave and Wenger 1990). This approach to learning 'in' science and 'in' nature includes scientists or other experts as part of the physical and social learning environment.

3.2.1 Implementation in Schools on Board

For all programmes, consideration is given to both the physical and social aspects of the learning environment. The most distinguishing feature of the Schools on Board field programme is the uniqueness and authenticity of the settings and situations for learning. The field programme was designed to integrate participants directly in the research activities of an active Arctic research programme. The setting for the field programme is the Arctic and the *CCGS Amundsen*, state-of-the-art class 1,200 research icebreaker (Fig. 7) that hosts 40 scientists and 40 crew members. Schools on Board participants are considered part of the science team when they board the ship.

In the Arctic

Experiencing the Arctic is something that cannot be taught from a textbook or in a classroom. It is through this experience that participants gain a greater appreciation

Fig. 8 Stations at the 2010 Arctic Science Day at FortWhyte Alive (Winnipeg, CANADA) where scientists simulate Arctic fieldwork in areas of snow dynamics, contaminants, sedimentology and meteorology

and sensitivity for the impacts of climate change on northern communities and the Arctic marine ecosystem. Although an authentic Arctic experience is unique to the field programme, emphasis on place-based learning influences selection of settings for youth forums and Arctic Science Days (Fig. 8). These settings include both school-based and off-site laboratories and outdoor spaces. Youth forums and science days can simulate Arctic conditions if their geographic location allows. Many Canadian cities and communities have similar conditions to the Arctic during the winter months, allowing for many opportunities to bring researchers together with students to simulate Arctic fieldwork in 1-day events.

In a Research Environment

Living and working on a research icebreaker creates a unique learning environment where participants can be immersed in scientific inquiry. The science teams include nationally and internationally recognised senior scientists, graduate students and technicians. Living on the ship exposes students to ‘life at sea’, the protocol of the Canadian Coast Guard, and life as a scientist. An extended stay on the ship exposes students and teachers to the interconnectedness of scientific researchers, the creativity and the teamwork required to understand climate change. The participants engage in scientific dialogue with scientists and witness the scientists' passion and commitment to their research. Unstructured interactions with scientists during their daily routine present participants with a unique glimpse of life as a scientist and the culture of research and fieldwork. The programme plan includes activities from 8:30 am till 10:30 pm each day. This 'full' itinerary introduces participants to the reality of working in the field, where every moment counts and research agendas take priority over weekends and free time.

The youth forums and Arctic Science Days bring students and scientists together in dialogue and hands-on research activities that simulate research activities in the Arctic.

In a Social Learning Environment

Attention to group dynamics during planning and implementation of programmes fosters positive interactions with scientists and other participants. Attention to group dynamics for the field programme include email activities prior to the field programme to build a team identity; pre-assigning small groups for fieldwork and activities to ensure everyone has the opportunity to work with each person during the course of the programme; pre-assigning roommates; planning fun and interactive activities; and implementing a variety of working scenarios, i.e. individual, pairs, small groups, large group, student-teacher pairs and student-scientist pairs.

Similar to Jarrett and Burnley (2010), participants welcome a fun and playful learning environment, especially with regard to science, which is too often taught in a very serious manner. This observation is corroborated by participant evaluations where 20 of the 30 participants in the last 3 years of field programmes attribute 'fun' to the personal impact statements and reasons why the programme exceeded their expectations. Making allowances for social interactions and creating field experiences with scientists provide opportunities for students and teachers to get personal experience with both the work and social aspects of fun and the role of playfulness in scientific thinking.

3.3 Criterion #3: Educating For the Environment and Science

This criterion relates primarily to the context or issues related to scientific inquiry and the environment. It includes processes such as critical reflection, problem-solving and decision-making. This is an action-oriented criterion that is aimed at encouraging pro-science and/or pro-environmental behaviours. It suggests that quality ESE programmes include activities that encourage learners to examine and challenge attitudes, values and perceptions about the environment, the nature of science and the relevance in scientific research. Educating 'for' the environment and 'for' science encourages the learner to take ownership or personal responsibility of their learning and apply this learning to real life situations and personal lifestyle and career choices.

3.3.1 Implementation in Schools on Board

The unifying theme of climate change provides an environmental context to the scientific research programme and is a major theme for all Schools on Board programmes.

Field participants are expected to keep a journal and contribute to the expedition logbook by working with a partner to prepare a dispatch (daily journal entry) for one of the days in the field programme. These activities involve reflection on what they learned and how they can best share it with others. All participants are required to prepare a presentation during the field programme. Their commitment to communicate their experience and raise awareness of climate change translates into numerous presentations delivered upon their return.

Problem-solving and decision-making activities related to climate change include discussions on adaptation and mitigation, sustainable development in the Arctic, sovereignty and the role of science in policymaking. A role-play activity related to economic development in the Arctic has been used to introduce students to the numerous issues faced by northerners as they attempt to balance concerns for economic growth with concerns for the environment. Meetings with community leaders involved in socio-economic development and resource management in the Arctic expose field participants to the complexity of these issues and socio-economic and political aspects indirectly related to climate change research.

These activities encourage students and teachers to critically examine the issues and challenge their own assumptions, attitudes and values related to climate change and scientific inquiry. The Arctic Climate Change Youth Forum dedicates half of the programme to science and the other half to issues related to environment, scientific inquiry and climate change (Fig. 9).

This focus on leadership and communication skills empowers participants to become involved in scientific outreach; provides them with skills, tools and opportunities to practise presentations; and reinforces the idea that they can play an important role in educating themselves and others.

4 Evaluation

Evaluation of Schools on Board programmes is both informal and structured. The informal or formative evaluation is ongoing and starts in the early stages of programme development, with consultations with scientists and educators to ensure the programmes meet expectations of the various stakeholders. This consultation helps

Fig. 9 The Arctic Climate Change Youth Forum dedicates half of the one-day programme to science and the other half to issues related to environment, scientific inquiry, and climate change (Photo credit: Schools on Board)

us to anticipate and overcome possible barriers. Informal evaluation also occurs during the implementation process. Backup plans and changes are implemented as required. During the field programme, open communication, frequent orientations and evening debriefings provided opportunities for informal evaluation in the field.

Structured evaluations for the field programme include questionnaires with self-rating scales (Table 2) and open-ended questions to evaluate impacts and expectations. A different questionnaire is designed for each of the following:

- Participants (students and teachers) – given on the first day of the programme and participants are asked to complete them on an ongoing basis
- Schools – given 3 months following the field programme to allow schools to implement their outreach plans and participant presentations
- Scientists – given after our departure from the ship

The evaluation process is used primarily for programme planning. Data collected on impacts and outcomes will soon be available in a full report (Barber, L. in prep). Preliminary findings reveal self-reported gains in knowledge and interest for all of the categories listed in Table 2. Due to space limitations, only the results for science inquiry, marine geology and interest in research are presented (as examples) in Figs. 10, 11 and 12.

Table 2 Self-assessment rating scale included in the participant evaluation

Science, engineering and research	Knowledge level prior to programme										Knowledge level after programme									
Scientific inquiry/nature of science	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Physical oceanography	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Marine biology – zoology	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Benthic ecology	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Marine geology	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Contaminants in the Arctic	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Chemistry in the Arctic research	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Arctic geography	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Arctic climate change	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Role of science in policymaking	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Traditional knowledge	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10

Science, engineering and research	Interest level prior to programme										Interest level after programme									
Natural sciences	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Engineering	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Research	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Other	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
Other	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10

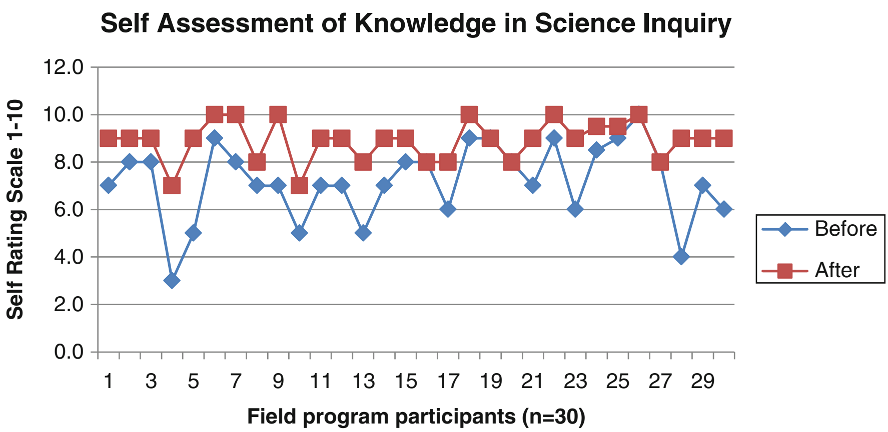

Fig. 10 Participants evaluate their level of knowledge related to science inquiry before and after the field programme. Most participants (25/30) reported a gain in knowledge, with 5 indicating no change

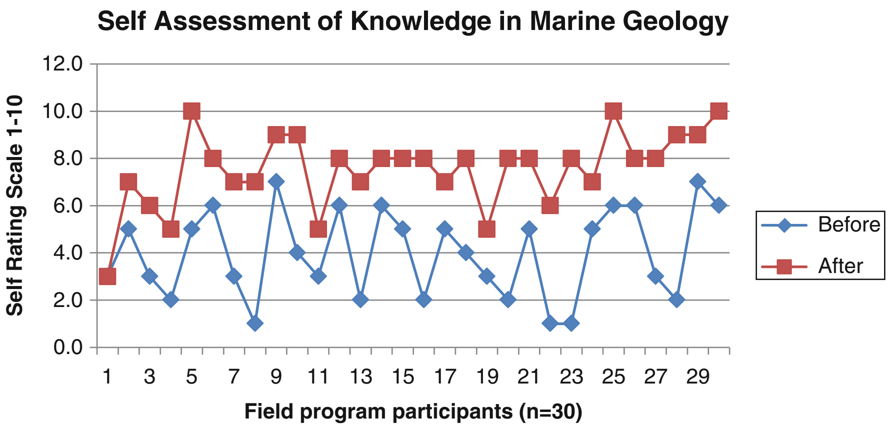

Fig. 11 Participants evaluate their level of knowledge related to marine geology before and after the field programme. All participants reported a gain in knowledge

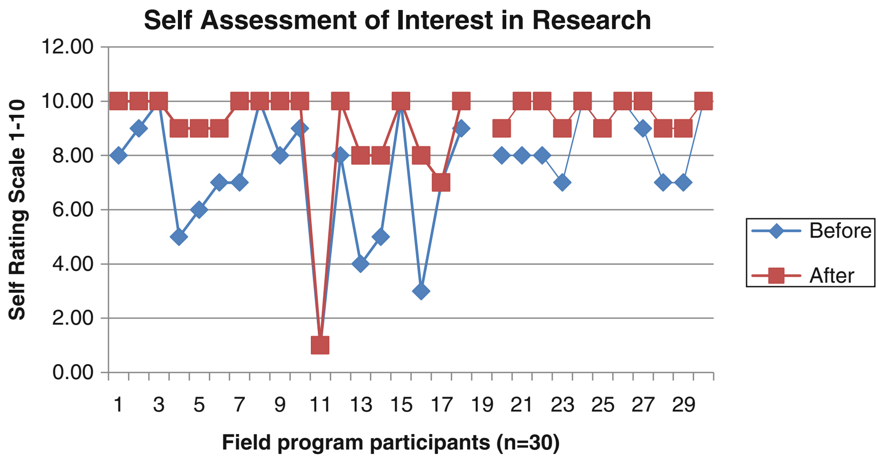

Fig. 12 Participants evaluate their level of interest in research before and after the field programme. Most participants (20/29) reported an increase in interest, and 8 indicated no change; however, 6 of those 8 were already at 10 prior to the programme

The report will show similar findings in all other categories of knowledge identified in Table 2. Despite the limitations of self-assessments in level of knowledge, these findings provide strong evidence from the participants' perspective, of knowledge gain through the field experience.

One of the goals of the programme is to promote science and inspire the next generation of researchers. Preliminary findings reveal an increase in participants' interest in natural sciences, research and engineering at the end of the field programme.

Preliminary findings of open-ended questions suggest that all participants, regardless of culture, gender or grade level, claim positive impacts from the field experience. This claim is supported by responses provided in the open-ended question by students and teachers. When asked: 'Did the programme meet, exceed, or fall short of your expectations? Why?' 29 of the 30 participants indicated that the programme exceeded their expectations, and one participant indicated that the programme met their expectation. The three mostly cited reasons for the programme exceeding expectations were the very hands-on nature of the programme (23/29), positive interactions with scientists in the field (23/29) and the 'fun factor' (20/29). With regard to personal impacts of the programme, 19/30 indicated that the programme impacted them in a profound and transformative way and influenced their plans for the future.

Measuring outcomes of the Schools on Board programme is an ongoing challenge, as many of these impacts are not easily measured or described.

5 Implications for Wider Practice and Conclusion

Complex environmental issues such as global climate change are evidence that ecological issues are societal problems that require an environmentally, scientifically and ecologically literate citizenry capable of making decision and judgements about, in and for the environment.

This chapter has described the approach used to plan, implement and evaluate the Schools on Board programme. It was only through a critical evaluation of the programme undertaken for a Master's thesis that I discovered the breadth of opportunities that content, setting and context present for planning our experiential programmes. Other practitioners may find this action research approach to programme or practitioner evaluation helpful.

The criteria described in this chapter do not dictate or prescribe a recipe for success. Rather, they identify factors regarding content, setting and context that contribute to learning and result in better educational programmes. As an outreach provider working in a science community, it is important that I find common language to communicate with educators – to find the connections to curriculum while not being restricted by it. Educators are not always up to date with current research and fields of study such as remote sensing, biogeochemistry, meteorology, thermodynamics and paleoclimatology. Yet, these are the growing fields that create new and exciting opportunities for students today who will be our researchers of tomorrow. This gap between what is being taught in schools and the research that is being conducted to study Arctic marine and Earth systems fuels the rationale for creating more opportunities for scientist to interact with students and teachers both in the field and in the classrooms.

Bridging scientific research to education through experiential programmes requires attention to risk management and re-evaluation of institutional restrictions on the participation of teachers and students in these types of activities.

As I write this chapter, the international scientific community is considering the merit of recognising the 'Anthropocene', a term popularised by Dutch chemist Paul Crutzen, as a new geologic epoch. This recognition that humanity is leaving a permanent mark and changing the planet on a global scale requires a shift in thinking about our relationship with the natural world. We all have a role to play in becoming educated and educating others to become more environmentally conscious of the finite and fragile nature of our habitat on this planet. This responsibility extends beyond the public education system and includes efforts of scientists to inform the public of their research and inspire the next generation of scientists and policymakers. The need to promote geosciences both in and out of classrooms has never been more timely or relevant.

Overview

Background and Motivation

– Global concern for climate change and the impact on the environment and society is driving a growing interest in environmental research and a corresponding demand for scientific outreach.
– The Schools on Board programme is a scientific outreach programme spearheaded by Canadian Arctic researchers committed to bridging Arctic marine sciences and climate change research to classroom education.
– The goals of the programme are to inform and educate the public and generate curiosity and interest in science-related careers.
– The Schools on Board programmes have been replicated with success and therefore can be models for others to use to develop similar programmes.

Innovation and Findings

– The programme focuses on inquiry-based learning through authentic and simulated science experiences.
– The key components include an Arctic field programme for high school students and teachers, on board a research icebreaker during a scientific expedition; an Arctic Climate Change Youth Forum; and Arctic Science Days.
– The planning framework focuses on three criteria: educating 'about', 'in' and 'for' Arctic climate change research.
– Despite challenges inherent in assessing experiential learning, programme evaluations reveal that students and teachers benefit from learning science by 'doing' science and interacting with scientists in real or simulated science experiences.

(continued)

(continued)

Implications for Wider Practice

The Schools on Board case study demonstrates that:

– Climate change is a unifying theme that brings together multiple perspectives and connects scientific research to many programmes in schools today – e.g. biology, earth sciences, history, political sciences, current topics, world issues, geography and social sciences.
– It is possible to plan and implement a successful field programme for high school students and teachers on board a working icebreaker or field expedition.
– The risks associated with field experiences are manageable. Schools should re-evaluate risk management policies to ensure that they are flexible and accommodating to these unique learning opportunities.
– Scientific outreach in formal education involves scientists and educators working together towards shared and complementary goals. An understanding of motivations, limitations and expectations contributes to successful partnerships and initiatives.

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Using Guided Inquiry Tools with Online Geosciences Data from the Great Lakes

Sandra Rutherford

1 Introduction

Earth science education has been on the minds of many organizations over the last decade. In 2001, a conference was held in Snowmass, Colorado, to form an action plan to change Earth and space science education across the nation (Barstow and Geary 2001). This call for change has been followed by numerous other documents, such as the Essential Literary Principles of the Ocean, Great Lakes, and Climate and the Earth Science Literacy Principles: The Big Ideas and Supporting Concepts of Earth Science (National Geographic Society 2004; Ohio Sea Grant 2010; US Global Change Research Program 2009; Earth Science Literacy Initiative 2010). Also, since 2001, the American Geological Institute, AGI, has been regularly reporting on the status of the geosciences workforce and education (AGI 2009), thereby keeping the focus on improving Earth and space science education with data that can be used by different organizations. The report *Revolutionizing Earth System Science Education for the 21st Century* came out in 2007, and authors Hoffman and Barstow have shown in this report that although there have been significant improvements occurring in several states since 2001, more still needs to happen.

Recently, the new Common Core State Standards for Math and English language have been formally adopted by all but ten states: Alaska, American Samoa Islands, Guam and the Northern Mariana Islands, Minnesota, Montana, Nebraska, Puerto Rico, Texas, and Virginia (Common Core 2011). The intent is that these standards will provide consistent appropriate benchmarks for all students, regardless of where they live. In July 2011, the new *Framework for K-12 Science Education* was released

S. Rutherford (✉)
Wisconsin Center for Education Research, University of Wisconsin-Madison,
Madison, WI, USA
e-mail: srutherford@wisc.edu

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which is being used by Achieve, Inc. to produce new standards for K-12 science education (Next Generation 2011). These new science standards are expected to be included in the Common Core State Standards.

Documents such as the Earth Science Literacy Principles indicate that Earth science investigations take many different forms and that multiple lines of evidence must be collected. This evidence often comes in the form of data. The *Framework for K-12 Science Education* (2011, p. 3–5) also lists the eight practices to be essential elements of the K-12 science and engineering curriculum:

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics, information and computer technology, and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

The Earth Science Literacy Principles and the new science framework both suggest the importance of using data and data analysis to inform science learning. The analysis and interpretation of data was highlighted by Manduca et al. (2002) as one of the skills (e.g., quantification, graphical) necessary to lead students to becoming a "geosciences expert." They also suggested that it is important to create learning environments which "fosters students' ability to use and understand visualizations and other representations of data." Manduca and Mogk (2002, p. 2) cite advantages of using data in science education which are summarized by Ledley et al. (2008):

- Students address real-world problems.
- Students critically evaluate the validity of the data.
- Students develop and support a conclusion to their question using the data.

These key reports, the *National Science Education Standards*, *Benchmarks for Science Literacy*, the *Revolution in Earth and Space Science Education*, and *Revolutionizing Earth System Science Education for the 21st Century*, relate the importance of inquiry-based activities, and inquiry requires access to data (NRC 1996; AAAS 1993; Barstow and Geary 2001; Hoffman and Barstow 2007).

Even though it is important to have students analyze and interpret data, it became apparent that data is actually not all that accessible for many teachers and their students. Therefore, Ledley et al. (2008) suggested the need to ensure accessible access to data for use by teachers and students in inquiry-based activities. Accessibility, as well as developing curriculum that uses data for teachers, has been a goal of many. Zalles et al. (2007) developed inquiry-based curriculum for climate and plate boundaries, and although they were successful in the development, they found implementation a challenge. For example, their students were not prepared to work with Excel. A second data-based curriculum, the Earth Exploration Toolbook (http://serc.carleton.edu/eet/), is a collection of online Earth system science activities.

Each activity introduces scientific data sets and analysis tools that enable users to explore some aspect of the Earth system. There are also links to Using Data in the Classroom and Teaching with Data, Models, and Simulations webpages. However, there is no discussion as to whether students or teachers had difficulty with the format, data use, or technical issues such as Excel.

Manduca and Mogk (2003), working with undergraduate students, discovered "at present the strongest evidence that using data improves learning comes from the integrated assessment of skilled faculty observing students in their courses." Using data in the classroom benefits students when they gain scientific habits of the mind and be able to critically evaluate evidence and solve problems. Swenson and Kastens (2011) point out that numerous studies have been done on students' understanding of data but that this research was conducted on students collecting the data themselves. However, little research has occurred on students' learning of data that is "professionally collected data" (Swenson and Kastens 2011). Swenson and Kastens (2011) restricted their study to students' reactions to using online data that was collected in the form of data visualizations and "professionally collected data." There are starting to be many more webpages where one can find geosciences data, some with developed curriculum to accompany the data that is inquiry-based, but there are few studies that have researched students' use and understanding of online geosciences data. This is obviously an area that needs more research in challenges of implementation. More research has been done examining students using the different tools for representations. For example, one might turn to research on student learning with respect to graphing and interpretation of graphs, an active area of research for some time with both pre-service elementary teachers and K-12 students in the mathematics education journals, as a predictor of students' ability to use data. A recent article by Szyjka et al. (2011) uses cognitive and attitude predictors to determine line graphing achievement among elementary pre-service teachers. They indicate that construction and interpretation of a variety of graphs are an integral part of inquiry-based science education. They also note that pre-service teachers are not prepared to teach interpretation of graphs in science because they lack the knowledge and skills to read and interpret graphs. They suggest that teachers are more likely to teach graphing if they are involved with graphing as part of their inquiry science activities and receive more exposure to "authentic" science activities or tasks.

To wrestle with this challenge of accessibility of geosciences data, we decided to create the *Teaching with Great Lakes Data* website. The *Teaching with Great Lakes Data* website has authentic data sets available for teachers and is described below. A guided inquiry tool called the Virtual Vee Map is available on the *Teaching with Great Lakes Data* website (Michigan Sea Grant 2010) for teachers to use and is also described. A Masters of Earth Science Education graduate student did a small case study in a middle school classroom to determine if the students could use the Virtual Vee Map. Pre-service elementary education teacher's Vee Maps were also analyzed for their ability to write a "testable" question. These two cases reveal some barriers in using geosciences online data. Finally, other methods for using data in the classroom will be discussed.

2 Teaching with Great Lakes Data: An Example

In order to examine the challenges of implementing the use of real-world data into classroom teaching, I share an example of an online data and curriculum resource *Teaching with Great Lakes Data*. The motivation for creating this site was to provide teachers with professional data in a useable form and the instructional support to adopt in their own practice. However, implementation proved to be a challenge.

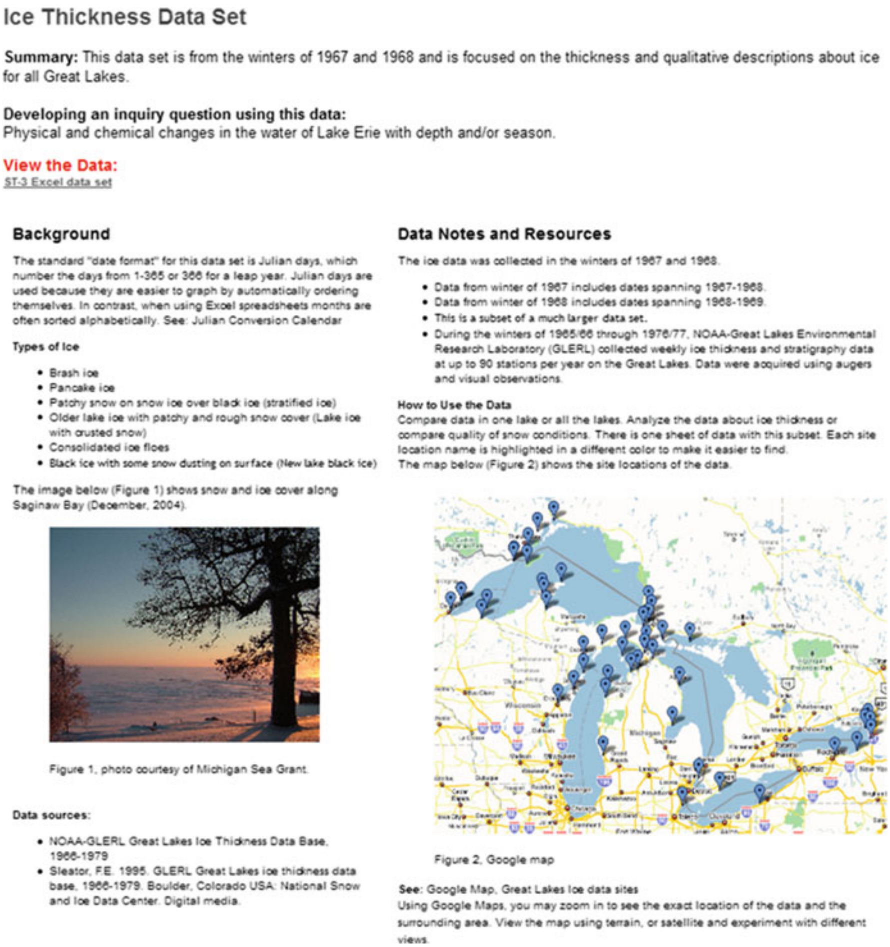
2.1 *Description of* Teaching with Great Lakes Data *Website*

A collaborative relationship among Eastern Michigan University (EMU), Michigan Sea Grant (http://www.miseagrant.umich.edu), the National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (NOAA-GLERL, www.glerl.noaa.gov), the Center for Ocean Science Education Excellence- Great Lakes (COSEE-Great Lakes (http://coseegreatlakes.net)), and the Great Lakes Observing System (GLOS, http://glos.us) was forged to develop a web portal with data sets, inquiry and assessment tools, and lessons and activities.

The web portal was structured to make guided learning activities easy to navigate and implement in the classroom. The main content areas on the website are structured lesson activities, data sets, and inquiry tools and resources. The majority of the data for this website has been compiled by scientists at NOAA-GLERL. Data was gathered from buoys, satellites, and other monitoring devices as part of a regional and global monitoring effort. NOAA-GLERL has both historical and real-time data available. However, the format of the data was not originally ideal for educational purposes. Pre-service teachers from Eastern Michigan University worked with NOAA-GLERL scientists to extract and modify the data sets that research scientists provided. Data was transferred to a spreadsheet format. Subsets were extracted from large data sets to increase accessibility, specifically for 5–12 educators and students.

The data sets and lesson materials are provided in four main modules: Earth Science, Physical Science, Life Science, and Social Science. The modules contain data sets and resources about Great Lakes facts, temperature, precipitation, water level, water flow, dissolved oxygen, Secchi depth (a measure of water clarity), light levels, turbidity, specific conductivity, pH levels, chlorophyll levels, and phosphorus levels. There are also data sets and resources about populations of plankton, algae, invasive mussels, and fishes, fish habitat, and the impact of ballast water from ships. The abundance of out-migrating Chinook salmon smolts, sampling of three forage fish species, and commercial and recreational fish harvests are included. Finally, there are data sets and resources about healthy beaches such as harmful algal blooms, E. coli concentrations, beach litter, and toxin levels in fish.

Each data set is linked from a main webpage. This page includes a link to the data set, a summary of the data set, and sample inquiry questions. Also included is background material (see example in Fig. 1) that provides an outline of the data set,



Ice Thickness Data Set

Summary: This data set is from the winters of 1967 and 1968 and is focused on the thickness and qualitative descriptions about ice for all Great Lakes.

Developing an inquiry question using this data:
Physical and chemical changes in the water of Lake Erie with depth and/or season.

View the Data:
ST-3 Excel data set

Background

The standard "date format" for this data set is Julian days, which number the days from 1-365 or 366 for a leap year. Julian days are used because they are easier to graph by automatically ordering themselves. In contrast, when using Excel spreadsheets months are often sorted alphabetically. See: Julian Conversion Calendar

Types of Ice

- Brash ice
- Pancake ice
- Patchy snow on snow ice over black ice (stratified ice)
- Older lake ice with patchy and rough snow cover (Lake ice with crusted snow)
- Consolidated ice floes
- Black ice with some snow dusting on surface (New lake black ice)

The image below (Figure 1) shows snow and ice cover along Saginaw Bay (December, 2004).

Figure 1, photo courtesy of Michigan Sea Grant.

Data sources:

- NOAA-GLERL Great Lakes Ice Thickness Data Base, 1966-1979
- Sleator, F.E. 1995. GLERL Great Lakes ice thickness data base, 1966-1979. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Data Notes and Resources

The ice data was collected in the winters of 1967 and 1968.

- Data from winter of 1967 includes dates spanning 1967-1968.
- Data from winter of 1968 includes dates spanning 1968-1969.
- This is a subset of a much larger data set.
- During the winters of 1965/66 through 1976/77, NOAA-Great Lakes Environmental Research Laboratory (GLERL) collected weekly ice thickness and stratigraphy data at up to 90 stations per year on the Great Lakes. Data were acquired using augers and visual observations.

How to Use the Data
Compare data in one lake or all the lakes. Analyze the data about ice thickness or compare quality of snow conditions. There is one sheet of data with this subset. Each site location name is highlighted in a different color to make it easier to find.
The map below (Figure 2) shows the site locations of the data.

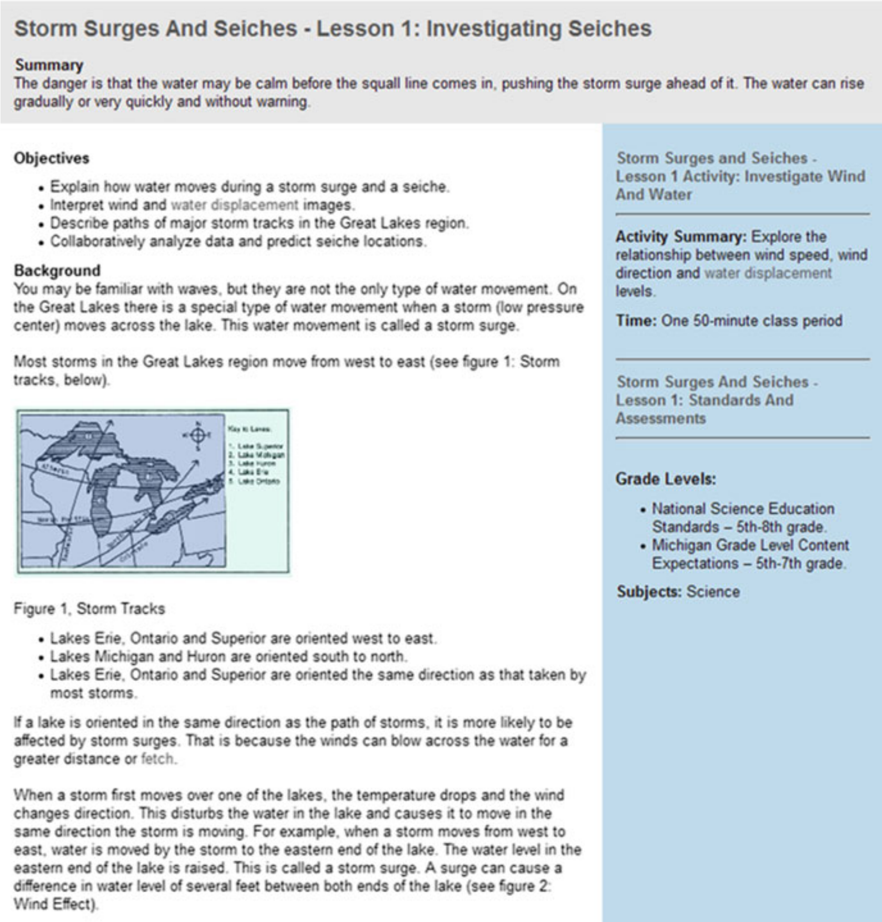
Figure 2. Google map

See: Google Map, Great Lakes Ice data sites
Using Google Maps, you may zoom in to see the exact location of the data and the surrounding area. View the map using terrain, or satellite and experiment with different views.

Fig. 1 Screenshot of the background information from the Ice Thickness data set

the concepts surrounding the data, calculations that were provided in the data, a map of where the data was collected (if available), the purpose and methods of the research, graphics, still pictures, fact sheets, and videos (if available). The background section also provides topical information (e.g., water quality), suggestions of how the data can be used and how data sets can be compared with each other or used together, and links to additional information.

The structured lessons and activities on this website are fully developed and ready to use (Fig. 2). The lesson topics are dead zones, fisheries, storm surges, and climate and weather. They are aligned for middle school; however, these lessons can be adapted for use by high school teachers. Included in each lesson is background information on broad scientific concepts and hands-on learning activities. Each lesson comes complete with the lesson plan, downloadable materials needed for the lesson,



Storm Surges And Seiches - Lesson 1: Investigating Seiches

Summary
The danger is that the water may be calm before the squall line comes in, pushing the storm surge ahead of it. The water can rise gradually or very quickly and without warning.

Objectives

- Explain how water moves during a storm surge and a seiche.
- Interpret wind and water displacement images.
- Describe paths of major storm tracks in the Great Lakes region.
- Collaboratively analyze data and predict seiche locations.

Background
You may be familiar with waves, but they are not the only type of water movement. On the Great Lakes there is a special type of water movement when a storm (low pressure center) moves across the lake. This water movement is called a storm surge.

Most storms in the Great Lakes region move from west to east (see figure 1: Storm tracks, below).

Figure 1, Storm Tracks

- Lakes Erie, Ontario and Superior are oriented west to east.
- Lakes Michigan and Huron are oriented south to north.
- Lakes Erie, Ontario and Superior are oriented the same direction as that taken by most storms.

If a lake is oriented in the same direction as the path of storms, it is more likely to be affected by storm surges. That is because the winds can blow across the water for a greater distance or fetch.

When a storm first moves over one of the lakes, the temperature drops and the wind changes direction. This disturbs the water in the lake and causes it to move in the same direction the storm is moving. For example, when a storm moves from west to east, water is moved by the storm to the eastern end of the lake. The water level in the eastern end of the lake is raised. This is called a storm surge. A surge can cause a difference in water level of several feet between both ends of the lake (see figure 2: Wind Effect).

Storm Surges and Seiches - Lesson 1 Activity: Investigate Wind And Water

Activity Summary: Explore the relationship between wind speed, wind direction and water displacement levels.

Time: One 50-minute class period

Storm Surges And Seiches - Lesson 1: Standards And Assessments

Grade Levels:

- National Science Education Standards – 5th-8th grade.
- Michigan Grade Level Content Expectations – 5th-7th grade.

Subjects: Science

Fig. 2 Screenshot of the Great Lakes lesson about storm surges and seiches

and standards and assessment tools. All of the lessons have been aligned to the national science standards (NRC 1996) and with the Great Lakes Literacy Principles (http://greatlakesliteracy.net/).

2.2 *Description of Guided Inquiry Tools*

For some time, all major science education reform documents have called for a shift in emphasis to more inquiry-based instruction in science classrooms (AAAS 1993; NRC 1996, 2011). This shift requires teachers to generate instructional experiences that provide students with the opportunity to engage in scientific phenomena through observations and data analysis. Colburn (2000) states that his "own definition of inquiry-based instruction is the creation of a classroom where students are engaged in essentially open-ended, student centered, hands-on activities." However, not all classrooms are doing inquiry-based instruction as Colburn defines it, and teaching science can range from a worksheet with no inquiry (structured inquiry) to a "Sludge Test" where students need to determine what is in the sludge (open inquiry). Thus, in practice, inquiry may need to be gradually infused through increasing levels of teacher direction, i.e., scaffolding (NRC 2000; Eick et al. 2005; Bell et al. 2005).

The *Teaching with Great Lakes Data* website makes the Virtual Vee Map guided inquiry tool available to teachers to use. The Vee Map was introduced in 1977 by Gowin as an alternative to the traditional laboratory report and is described as a tool that is used during laboratory exercises to guide students' thinking and learning (Roehrig et al. 2001). Coffman and Riggs (2006) successfully did this guided inquiry activity with pre-service elementary teachers by revising the original Vee Map to suit the online environment. The different parts of the Vee Map are shown in Fig. 3 and are connected; by starting with an inquiry question and where the pre-service elementary students describe known concepts that support their investigation by constructing a concept map. Roehrig et al. (2001) suggest that the concept map helps students begin to understand the relationship of the concepts to the inquiry question. These graphic organizers or thinking maps as concept maps are sometimes known to help the student then formulate a hypothesis, something that Roehrig et al. (2001) did not do but that Coffman and Riggs (2006) added. This first part to the Virtual Vee Map is known as the conceptual side. Only after the students have confirmed their question and formulated their hypothesis can they move to the methodological side of the Virtual Vee Map. Normally the events area at the bottom of the Vee is where a student can write out the procedure or draw a laboratory setup however; this is where Coffman and Riggs (2006) had the pre-service elementary students investigate data sets or "professionally collected data," the term that Swenson and Kastens (2011) suggested. Next, they used the data from the websites to display the results of the virtual inquiry by developing a graph or table. Finally, the pre-service elementary students complete their inquiry by writing a conclusion and answering their question.

2.2.1 Middle School Students

Coffman and Riggs (2006) asked in a survey the opinion of their Life Science for Elementary Teachers students in their study: What is the likelihood that you would have your students complete a Virtual Vee Map project like the one you completed? Only 62 % of the pre-service students felt likely to engage their students in the Virtual Vee Map project. Coffman and Riggs suggest this low percentage may be due to suitability of the Virtual Vee Map to upper- rather than lower-elementary grades. To determine if the Virtual Vee Map is suitable for upper-elementary grade students, Ann Marshall, a graduate student in the Master's of Earth Science Education program at Eastern Michigan University, decided to conduct a baseline study at a middle school in Michigan.

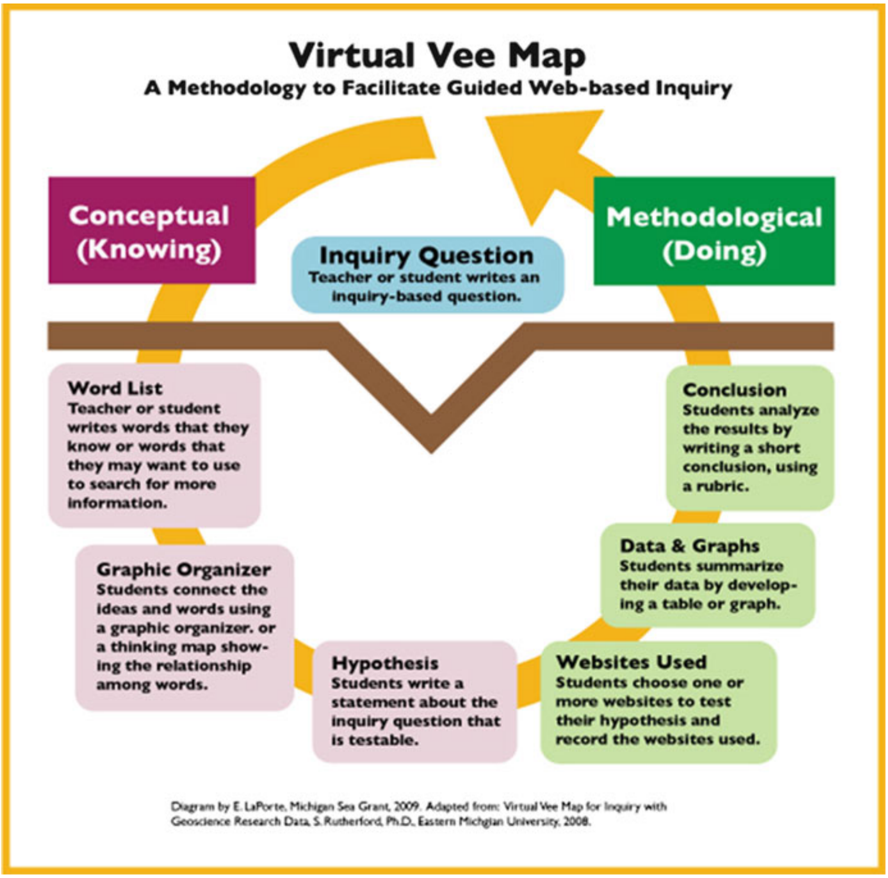


Fig. 3 Summary of the inquiry process of the Virtual Vee Map

Her project was done over the course of 3 days. Six 7th grade science classrooms were divided up into two groups of three classes. One group was taught in a more traditional way with reading, following directions, and filling out a worksheet – structured inquiry. The other group was taught exactly the same content using a Virtual Vee Map guided inquiry method. The cooperating teacher divided the groups up according to her discretion, making sure there was an equal amount of all learning types in each group. In the traditional teaching method group, parental permission was received for 34 students. In the group where the guided inquiry teaching method was used, permission for 22 students was received.

The participants of this project were 7th graders in a public school in Michigan. According to the GreatSchools website (2011), these 7th graders scored below the state average in math, reading, and writing. This school's demographic makeup consists of 65 % White, 25 % Hispanic, 8 % African American, and <1 % Asian/Pacific Islander. The number of students eligible for free or reduced lunch is 57 %, which is higher than the state average. The attendance rate at this school is 98 % (Great Schools Inc. 2011).

The data sources for this project were a pre- and post-assessment, classroom work, and student interviews with guided questions. The activities used in this project for both groups of students were taken from the *Teaching with Great Lakes Data* website. The key concepts that were addressed in this project were how to interpret a graph, dissolved gases, density with respect to temperature, and biological concepts with respect to dissolved gases in water. The students were first given a pre-assessment survey, which consisted of 20 questions to determine how much students already knew and understood about the topics. Eleven of the twenty questions are in the style of the New York Regents prep exams (NYSED 2011), one question came from a quiz in the Physical Universe textbook (Beiser and Krauskopf 2006), and the eight remaining questions designed by Ann Marshall were Great Lakes and graphing specific. The same 20 questions were used in the post-assessment survey to gauge student learning after the classroom activity on the last day of the project. During the classroom activity, students were either given a worksheet or a Vee Map to complete, depending on which group they were in. Twenty students were also interviewed at the end of the classroom activities to further gauge student learning. Nine students were from the traditional teaching method group while the other 11 were from the guided inquiry teaching method group.

The pre-/post-questions and student interviews have been analyzed so far, and Table 1 shows the percentage of correct responses for five of the pre-/post-assessment questions that were considered to be about graphing.

During the interview, the students were asked a few questions about graphing. For the questions "What did you think of the activities that we did this week? What did you like the most? What did you like the least?" the responses were coded as to whether they liked graphing, did not like graphing, or said that graphing confused them. The group of students taught using the traditional teaching method was evenly distributed with respect to this question. Three students liked graphing, three students disliked graphing, and three students thought it was confusing. The group of 11 students taught using the guided inquiry teaching method mostly did not mention graphing. One student disliked graphing, one student thought it was confusing, and three liked graphing.

For the question "Does the horizontal line on a graph represent the *x*-axis or the *y*-axis?" both groups averaged 89 % correct with an answer of *x*-axis. Only one student from each group did not answer. When asked, "Does the vertical line on a graph represent the *x*-axis or *y*-axis?" again both groups responded similarly with 78 % of the students from the traditional teaching method responding correctly and 72 % of the students from the guided inquiry method.

When asked in the interview "What is the purpose of a legend on a graph?" the students either gave an answer that was correct, vague, or said they didn't know or gave no answer at all. From the traditional teaching group, 56 % of the students gave an answer that was considered correct because they noted that the colors on the legend were connected to the symbols on the graph. However, only 45 % of the students in the guided inquiry teaching method group made the connection between

Table 1 Pre-/post-assessment results for graphing type questions for both groups

Pre-/post-assessment questions about graphing	Traditional instruction			Guided inquiry instruction		
	Pre-assessment % of correct responses ($n = 34$)	Post-assessment % of correct responses ($n = 34$)	Percentage change	Pre-assessment % of correct responses ($n = 22$)	Post-assessment % of correct responses ($n = 22$)	Percentage change
1. Which graph shows that more grams of a substance can be dissolved in water as the water temperature increases?	82	67	−15	68	82	14
2. What is displayed on the *x*-axis?	76	88	12	86	86	0
3. What is displayed on the *y*-axis?	71	82	11	72	86	14
4. What is the purpose of the legend?	35	44	9	55	41	−14
5. What is the purpose of this graph?	38	64	26	68	68	0

colors on the legend with the symbol on the graph. This was confirmed with the pre-/post-assessment since the guided inquiry group did not improve on the post-assessment.

Finally, when asked “What should the title of the graph include?” a majority of the students from both teaching methods gave vague answers such as “What the graph is talking about” or “To show what you are graphing” or indicated they did not know. Only two students from the traditional teaching method group gave an example. “Like for example depth and temperature” and “If we were doing a graph about Lake Erie, it should say Lake Erie. And if we were doing fish vs. plants, then we would do something like Lake Erie fish vs. plants.” However, neither of these answers uses words such as variables or location.

Overall, the 7th grade students from the traditional teaching method showed they understood graphing a little better after the lessons. The Vee Map itself and using Excel was so confusing to the middle school students that there was not enough time left to teach the material using even the traditional teaching method. More research needs to be done to study the use of the guided inquiry Vee Map with upper-elementary grade students.

2.2.2 Pre-service Elementary Teachers

Coffman and Riggs (2006) noted that the pre-service elementary teachers in the Life Science for Elementary Teachers class “had difficulty designing a question to get started” on the Virtual Vee Map assignment. This is one aspect of the Virtual Vee Map that merits closer scrutiny. There are many types of questioning techniques that occur in a classroom. Teachers more often pose questions to their students, but students also pose questions to the teachers and to their peers. Teacher-posed questions typically serve formative and summative assessment needs (Marbach-Ad and Sokolove 2000; Keeling et al. 2009), whereas student-posed questions are aimed at resolving misunderstandings that arise within the lesson. On the other hand, the types of questions posed when practicing science are a bit more restrictive in that they should be “testable.” The National Research Council (2000, p. 24) defines scientifically oriented questions as those that “lend themselves to empirical investigations, and lead to gathering and using data to develop explanations for scientific phenomena.” Therefore, a “testable” question should not be a question where the answer is obtained through literature research but should be rather one in which an investigation can be designed and data gathered and analyzed to suggest a potential answer.

All inquiry activities start with a research question irrespective of the level of inquiry that students endeavor to answer through data analysis (Bell et al. 2005). Anderson and Krathwohl (2001) indicate that to generate a good research question the cognitive process of analyzing data is required. This skill must be developed, and until now science teacher preparation has not considered this aspect. Whereas research concerning questioning techniques is rather widespread (Wilen 1991; Costa and Kallick 2009), research regarding a teacher’s ability to generate research

Table 2 Scoring rubric for testable questions from Graves and Rutherford (2012)

Number of variables	
Score	**Description**
2	The question has **at least two clearly stated variables**
1	The question has **one clearly stated variable**

Structural quality	
Score	**Description**
3	The question is a well-written, **testable** question. The question has *no grammatical errors* and *specifies* the parameters of the investigation (i.e., reference to a specific lake, area, or dimension) and *states a cause/effect relationship* between two variables
2	The question is **testable but SHOULD BE modified**. The question has some *minor grammatical errors* (i.e., wording of the question should be improved) *OR* the question *does not specify* the parameters of the investigation *OR does not state a cause/effect relationship*
1	The question is **testable but NEEDS TO BE modified**. The question is deficient in *at least 2* of the following ways: 1. Has some *minor grammatical errors* 2. *Does not specify* the parameters of the investigation 3. *Does not state a cause/effect relationship*

questions does not exist. Additionally, pre-service science teachers do not usually engage in scientific research (Melear et al. 2000; Mugaloglu and Saribas 2010). Considering the emphasis on including more inquiry-based instruction into science classrooms, it would be best to provide pre-service teachers with authentic opportunities to improve their scientific inquiry skills.

To evaluate the questions, Graves and Rutherford (2012)) analyzed the Virtual Vee Map inquiry questions from the students in both the Life Science for Elementary Teachers and the Earth Science for Elementary Teachers courses at Eastern Michigan University. To do this they developed a rubric to score the questions. All questions were categorized as testable or non-testable questions. The non-testable questions were either poorly written questions (i.e., questions that made no sense as written) or were beyond the scope of science (i.e., questions lacked any measurable variables). Testable questions were further examined using the scoring rubric shown in Table 2.. The rubric was objectively designed to gauge the students' ability to identify measureable variables, state specific parameters for the investigation, identify potential relationships between the variables, and communicate their analysis (Graves and Rutherford 2012).

The main emphasis of the study was to determine if pre-service elementary teachers were able to generate "testable questions." This was accomplished by examining inquiry questions from a Virtual Vee Map assignment in their courses. The majority of students from both courses clearly stated two variables in their testable questions. The structural quality of the testable questions (see scoring rubric in Table 2) was also examined, and only 6 % of the students from both courses wrote testable questions that scored 3 points. Therefore, 94 % of the students wrote testable questions that had grammatical errors, did not indicate specific parameters, or did not show a cause/effect relationship. The majority of students (57 %) wrote questions that were testable but needed to be modified to be deemed acceptable as decided by the scoring rubric (scored only 1 of a possible 3 points for structural quality) (Graves and Rutherford 2012).

Their study intended to answer the question, "Can pre-service elementary teachers write a testable question while using online data sets especially prepared for teachers?" (Graves and Rutherford 2012). Most major education reform documents indicate that for science literacy to be successful inquiry-based instruction should be used (AAAS 1993; NRC 1996). Therefore, science teachers must understand what science inquiry-based instruction involves if they are expected to use it in their classrooms. Two major aspects of inquiry-based instruction include developing a scientifically relevant ("testable") question(s) and investigating data to answer the question(s) (Eick et al. 2005; Bell et al. 2005). Most of the pre-service elementary teachers (80 % of the participants) were able to produce testable questions using the data sets available to them. However, there is always room for improvement (Graves and Rutherford 2012).

Graves and Rutherford (2012) observed that most of the pre-service teachers did not necessarily catch the cause and effect part of a testable question and neither did they compose a question that was easily understood. In describing a college sophomore student field trip, Burrowes (2007) finds that "students have difficulty formulating a proximate cause question that they can study in the given time frame." Thus, if the elementary pre-service teachers could not write a high-level testable question, then how would they be able to teach this skill to their own students? Flannagan and McMillan (2009) suggest that more concrete strategies are needed to support elementary students in designing testable questions. More often elementary teachers conduct "cookbook labs" because there are not many opportunities to design their own investigations (Melear et al. 2000; Mugaloglu and Saribas 2010). Elementary students need a framework for developing their own testable questions but it appears so do their potential teachers. Not enough time is spent with pre-service elementary teachers discussing the nature of science and conducting research during their science education courses. Faculty need to realize that pre-service elementary teachers need as much support as elementary students in conducting investigations.

Utilizing real data online will help support all students to do inquiry with their investigations, especially if the students cannot get outside to collect the data themselves. However, teachers need to remind students to do the research necessary to answer their question instead of using one data set or website. Morgan and Hiebert (2010) suggest that more scaffolding is required to formulate good inquiry questions. A teacher can scaffold this activity by asking the students to pose three or four questions, and then asking them to defend the best question to pursue based on the available data and how interesting or worthwhile the question is.

3 Barriers to Success

Although the cases presented here are not a complete study of inquiry-based methods or graphing construction or interpretation of data, it does show that there needs to be much more research in these areas. Both pre-service elementary teachers and K-12 students have many barriers to successfully analyzing authentic data.

The elementary education pre-service teachers here at Eastern Michigan University regardless of their major or minor must all take a science sequence of four courses starting with Physics for Elementary Teachers, Chemistry for Elementary Teachers, Earth science for Elementary Teachers, and a content and science methods course combined entitled Life Science for Elementary Teachers. For mathematics, they take Problem Solving and Number Concepts for Elementary School Teachers and Mathematical Reasoning: Applications for Elementary School Teachers, and finally their mathematics methods course is Teaching Math in Elementary School. The prerequisites for both the science and mathematics courses are that they are taken in sequence. Teaching at the middle school requires a major or minor in a given area. In fact, many universities only require two content science classes. Therefore, one could believe this is quite a bit of mathematics and science for someone teaching grades K-5 which is what a licensed elementary education teacher can teach.

Since, Szyjka et al. (2011) indicate "graphing is considered more than a series of complex intellectual activities requiring individuals to read, comprehend and analyze visual forms of data, while at the same time being able to successfully construct graphical representation. Rather, graphing ability is viewed as part of a broader set of conditions linking affective and cognitive (person) factors to learning." And Seaman and Szydlik (2007) have shown through literature research that pre-service elementary teachers are "unsophisticated" or a "novice," whereas a mathematics student is "sophisticated" or an "expert" and that a novice tends to do mathematics by memorization. Therefore, Seaman and Szydlik (2007) suggest that pre-service teachers need to develop "the habits of mind of a mathematical thinker" and that this is imperative for mathematics content courses. If pre-service teachers view line graphing as a function of mathematics rather than inquiry-based science, then their "unfavorable attitudes toward aspects of mathematics as they were integrated into science" would lead them to dislike line graphing in mathematics as well (Szyjka et al. 2011). They also suggest that science methods could improve pre-service elementary teachers' performance in line graphing by incorporating a more general mathematics alongside graphing instruction. But learning how to do mathematics or teach it is generally not taught in science methods courses since this is the purview of that discipline.

Ellwein et al. (2011) recently gave a presentation that discussed data literacy. She indicated that pre-service elementary teachers can extrapolate; they understand slope but when probed deeper did not know which variable was independent or dependent. If pre-service elementary teachers cannot construct or interpret graphs, then how will they teach their own students? Is this the reason the students had such a difficult time in the middle school classroom we looked at?

4 Other Ways to Use Online Data in the Classroom

Kastens and Turrin (2010) published *Earth Science Puzzles*: *Making Meaning from Data* that uses data snippets the authors preselected. Brown (2011) says, “this terrific paperback guides teachers in developing students’ analytical skills. It presents six activities related to fundamental Earth science processes, such as earthquakes and weather, that can be used to teach students how to go beyond locating a data point on a graph to finding patterns in data and analyzing the meanings of those patterns. The authors provide all the tools teachers need to use these activities in their classrooms.”

Teachers also see the need to use “professionally collected data” in other ways. Lyndsey Manzo who teaches at Westerville North High School in Ohio suggested one way to use the *Teaching with Great Lakes Data* website in the classroom. She advocated when using the Temperature and Precipitation data set to do a jigsaw exercise whereby the students work in multiple groups. The students are grouped by lake: Lake Erie, Lake Superior, etc. In a class with 30 students, they will be in five groups, each with six students (Fig. 4). The students in each group will become experts on their specific lake.

After the Specific Lake Expert (A) groups have viewed at the data and graphed the water surface temperature for their lake, they were put into new groups (Fig. 5). The students in the Lake Comparison (B) groups can share what they discovered about their lake, look for patterns, and predict future trends.

Jack Ganse a teacher at Eldorado K-8 Middle School in Superior, Colorado, has the students graph data often as homework and do an analysis paragraph in the form of a masterpiece caption. There are also guidelines on his website to help the students: a Graphing Help Guide and a Masterpiece Caption Help Guide. An example

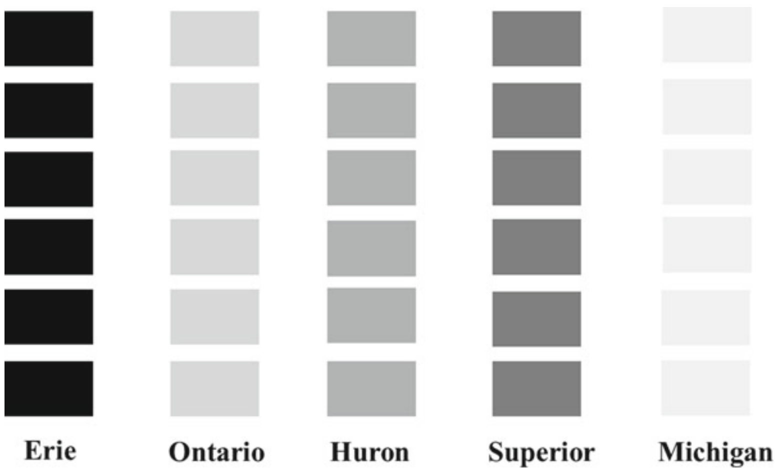


Fig. 4 Specific Lake Expert (A) groups

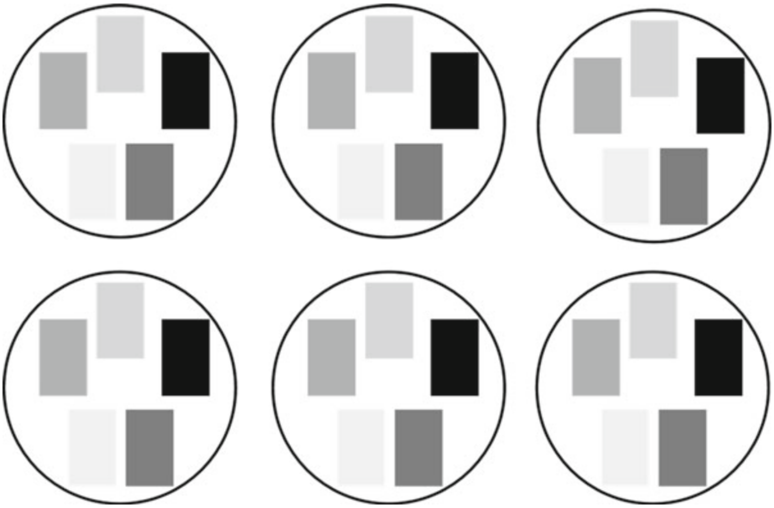


Fig. 5 Lake Comparison (B) groups

homework set is found http://schools.bvsd.org/eldorado/escience/science8/CompositionOfEarthsAtmosphere.pdf, and if you go to his website http://schools.bvsd.org/eldorado/escience/index.htm you can see the Help Guides as well as Graphing and Diagramming Resources. He tells the students that they "may create the graphs by hand or use software such as Microsoft Excel, Open Office, or Create A Graph," thus getting around the problem that Zalles et al. (2007) found with using Excel.

5 Conclusion

Kastens and Turrin (2010) acknowledge that "students should be able to tackle open-ended inquiries. Students should be capable of identifying a question, planning an inquiry to address that question, navigating their way through the relevant data, and interpreting subtle or complex data patterns in terms of causal processes." Although they do not explicitly say that students cannot really do all this, the production of these puzzles indicates that they believe a stepping stone toward this goal of open-ended inquiry is necessary. Because there have been very few studies with either K-12 students or pre-service elementary teachers with respect to data literacy, especially using data from online resources, and only Zalles et al. (2007) mentioned Excel use as a barrier, what are the other barriers?

Pre-service elementary teachers often lack math skills and dislike science. Pre-service elementary teachers and their students need more help with writing a testable question, with using technology, with constructing graphs, and other mathematics. Hence, this appears to be one of the drawbacks to using real data in the classroom. Ellwein et al. (2011) did indicate that in-service teachers see the importance to using data and sometimes feel strongly enough about it such that they make a point of integrating data into their classrooms. But others feel it is too difficult to do because their students lack the skills necessary to work with online data and curriculum is needed to help them use online data.

Overview

Background and Motivation

– Geoscience education advocates have been trying for the last decade to ensure that Earth science is actually taught in K-12 schools and that these classes are taught by qualified teachers. This will hopefully ensure a better prepared geosciences workforce.
– These goals have initiated a surge in research on how students learn Earth science and how best to teach it.
– To ensure that teachers and their students have access to data for use in inquiry-based activities a *Teaching with Great Lakes Data* website has been created.

Innovations and Findings

– The new *Teaching with Great Lakes Data* website is described along with a description of guided inquiry tools. The main content areas of the website are structured lesson activities, data sets, and inquiry tools and resources. The Virtual Vee Map is the guided inquiry tool that is used in this study. The Virtual Vee Map starts with an inquiry question. The students then describe known concepts that support their investigation by constructing a concept map. To answer their inquiry question, the students then locate professionally collected data which they then graph and analyze to answer their original inquiry question.
– A small study of middle school students was conducted using online geosciences data. For this study, the Virtual Vee Map teaching method is compared with a more traditional teaching method. The students tended to have difficulty with the inquiry teaching method as well as with almost all aspects of analyzing and interpreting data.
– The Virtual Vee Map starts with a "testable" question which is a scientifically oriented question that lends itself to an empirical investigation. College students who are studying to be teachers are known as pre-service teachers. For this second study, pre-service elementary teachers "testable" questions are analyzed. Although they can successfully write a testable question, they had difficulty writing a high-level one.

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Implications for Wider Practice

– Pre-service elementary teachers need more help with how to use online geosciences data in the classroom. K-12 students need more help with analyzing and interpreting data.
– Other ways to analyze professionally collected geosciences data are suggested. These include using more structured methods.
– This chapter points out that more research is needed with K-12 students and pre-service elementary teachers with respect to data literacy especially when using data from online resources.

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Part VI
Promoting Research-Enhanced Outreach

Communicating Climate Science from a Data-Centered Perspective

Matt Rogers

1 Introduction

Great advances have been made in the scientific understanding of the Earth's climate and the various physical processes that govern the complex interactions between the Earth's natural and anthropogenic components. Communicating the increasingly complex results of these advances, however, is a daunting task, and the rapid scientific advancements made have not always been matched by a similar increase in the *public* understanding of the Earth's climate. Exactly why communication between climate scientists and the general public breaks down is a topic of great interest, and effective techniques for scientists and educators to use to communicate climate science to the world are of increasing importance.

Perhaps one of the issues central to the perceived divide between climate scientists and the public at large is the differing nature in how scientists and the public perceive the results of scientific research. For both the scientist and the public, different frames of context and relevance are in play and can lead to considerable confusion and miscommunication. By looking into these epistemological issues in how scientists and the public understand scientific research, it may be possible to develop a new framework for scientists and educators to disseminate the results of scientific research in a manner that is more easily understood by the public.

Communicating the results of a scientific research project, to a nonscientific audience, is a difficult task to undertake, to be sure. To address this difficulty, scientists and educators engaged in ongoing education and outreach work can potentially use an inquiry-driven approach, utilizing the underlying data used in the scientific

M. Rogers (✉)
Cooperative Institute for Research in the Atmosphere,
Colorado State University, Fort Collins, CO, USA
e-mail: rogers@cira.colostate.edu

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research project, to more effectively communicate the research results as well as the fundamental ideas of climate science. By approaching the science content from the perspective of the observations, it may be possible to address the problem of context and relevance in a manner that greatly enhances the understanding of climate science and how to communicate it, for scientists, educators, and the public alike. We hope to look into this opportunity and to see how climate scientists could possibly reframe their efforts at education and outreach to better represent the science being done in this field.

2 Examples of the Status Quo

Nicholls and Kestin (1998) recount one example of communication between scientists and the public breaking down. In their commentary, they relay an anecdote about a scientific paper published by a colleague relating the possible impacts of an enhanced greenhouse effect to tropical storm formation. To Nicholls and Kestin, who attended a seminar by the paper's author, the study was found to be "uncontroversial," and of interest, with some increase in storm strength tied to the enhanced warming, barring unknown feedback effects. To the "amusement" of the authors, however, the local Melbourne, Australia, newspaper headline the next day summed up the seminar quite differently, with a headline promising "Super cyclones on horizon, say scientists."

That the newspaper could interpret the import of the seminar so differently than the scientists may not simply be a case of a reporter simply misunderstanding the proceedings of the seminar; in a comprehensive study of newspaper analysis of climate change, Antilla (2005) examines the constructive framework under which news articles on climate change topics are examined on the part of reporters and newswire services.

A common thread in both the Nicholls and Kestin (1998) and the Antilla (2005) studies is that differences in how scientists interpret scientific results versus how the public sees the same results are the root cause of misunderstanding and miscommunication of research results. Nicholls and Kestin (1998) draws from Fischhoff (1994) by noting that problems arise from issues of trust and context between scientist and audience, while Antilla (2005) notes that scientific research on climate change is constructed as a social problem (rather than a matter of scientific inquiry) in the sense that, quoting from Barnes (2003), the "idea that the social context of inquiry, rather than the world that is investigated, determines – constructs – knowledge." In this sense, to the public, it would seem that the actual science being disseminated becomes secondary to the context in which it is presented. Nicholls and Kestin (1998) discuss a further anecdote, in which an official forecast product, intended specifically for media release, from the Australian Bureau of Meteorology detailing a "strong likelihood of significantly drier-than-normal conditions" was criticized by the local media as exaggerating drought conditions – to the public, the results were widely interpreted as assuring drought conditions, while the scientists were qualifying a statistical increase in the chance for drought conditions. Again, the culprit of the miscommunication was a contextual difference in how scientists and their audience interpret certain words – in this case, the word "likely" – and led to misunderstanding. In this case, these miscommunications resulted in nothing more than mixed signals between a government agencies and users, but as Antilla (2005) demonstrated, the disconnect between the roles of context and relevance between what scientists say and what the public hears can be used to create a new emphasis that reshapes the content of the scientific discourse (e.g., an unwarranted emphasis on the consensus (or lack thereof) of climate scientists on the role of anthropogenic causes of climate change.)

3 Challenges to Overcome

The nature of this context gap is an area of active research for sociologists; for a climate scientist focused on environmental research, understanding the communication gap is likely not part of their research program. That such a gap in relevance and context exists, however, remains a challenge for the scientist to overcome in an attempt to present meaningful scientific research and improve the understanding of climate science in general.

From the contextual framework of the scientist, the details of the research, the uncertainties of the observations and the results, and the areas to which the results are applicable are self-evident and are often assumed (sometime erroneously) by the scientist to be likewise understood by the interested reader. For the educator, media representative, student, or member of the general public, however, this assumption may not be valid, and often *cannot* be valid, as understanding the full implications of a research report may require a level of knowledge and familiarity with the subject matter that is simply not realistic.

From the framework of the public, according to Antilla (2005), the research results are instead interpreted in the sense of "events" and "frames," wherein "events" are societal choices on which aspects of the world are of import and "frames" are the social understanding and relevance of how events relate to the reader. Scientific findings may therefore become events to be interpreted through the norms of societal relevance to the reader, and any mismatch between relevance to the scientist and relevance to the reader will likely lead to miscommunication. From the farmers' perspective, an "increased likelihood" of dry conditions may well be the same as definitely dry conditions if it means using different farming techniques to survive the next growing season, even if the qualifications apparent to the scientist are not apparent to the farmer.

Such miscommunications lead to an additional challenge for the climate scientist hoping to communicate research results. The difficulties encountered in engaging the public in climate science, and the aftermath of miscommunications encountered in the attempt, may discourage climate scientists from even trying in the first place. Betts (2011a) notes a "long-held view" within the scientific community that scientists attempting to engage the public on matters of climate and climate change will lose their impartiality while damaging the reputation and integrity of science on the whole. If successfully communicating climate science means learning new and unfamiliar contexts for communication while risking personal and institutional damage to the field of science, many scientists choose to avoid public commentary altogether.

Ultimately, however, this situation cannot stand – a withdrawal of the scientist from the public sphere leads only to a further disconnect between scientific research and the public opinion of science, to the detriment of both. Clearly, solutions to help bridge the gap in context and relevance must be sought out to continue to engage the public in understanding the methods and results of climate science.

4 Data-Centered Inquiry as a Strategy

One such solution that has been explored is the utility of using scientific data or observations (rather than the research results) as a method to create mutually intelligible context and therefore motivate public understanding. On their own, scientific observations (say, a temperature record for a certain weather station) have a clear context for scientist, educator, student, and the public alike and are comparatively easy to understand. If the research results are formulated in a manner that emphasizes the observations, and then seeks to explain the important trend or pattern in the observation through basic science principles, then it may be possible to craft a mutual context for understanding the data in a manner that also satisfies the need to communicate the results of the research. By providing the motivation to understand the research through the observations, not the results themselves, the pitfalls of disparate contextual understanding may perhaps be avoided.

In order to attempt this strategy, a few guidelines must be followed. First, the scientist must assess the needs and relevant issues of a specific audience (e.g., K-12 education or the general nontechnical public.) Central to these audiences are specific needs and relevancies (e.g., educational standards on the part of K-12 audiences) that can help to identify key relevancies and contextual frameworks. Additionally, the scientific observations themselves must be of some relevance to the intended audience, in order to utilize a shared context and relevance. Essential scientific principles and physical processes inherent to the research results must be distilled to a level that the intended audience can understand in the process of examining the observations. In presenting the observations and simplified physical processes, the integrity and impartiality of the scientific method must be maintained. And critically, collaboration with education and media specialists must be utilized, to gain continual feedback from the audience and ensure continued relevance as the observations are explored.

Presenting scientific research from the perspective of the data is rather a more involved process than simply presenting the results; the benefit of starting from a point of mutual relevance and context, however, can lead to a better understanding of the material and perhaps a decreased chance of miscommunication. The key difference between this approach and the approach of directly reporting on the results of research is that the focus for education and outreach is in understanding scientific concepts and fostering an appreciation for the scientific process; through application of this focus, the *ability* to understand the results, within a shared context, is attained.

5 Examples of Data-Centered Approaches to Understanding Climate Science

Fostering communication and mutual understanding between scientists and their intended audience is the first step of the data-centered approach. Nicholls and Kestin (1998) document an approach to make an intentional partnership between the Bureau of Meteorology forecasters and their end-user community to improve communication, create a mutual dialogue, and "share frustrations" that led to an improved understanding of fire weather forecasts.

Communicating the results of sophisticated research will require a more involved process, involving direct examination of the observations to provide the shared context needed to understand climate research. Betts (2011b) presents an example of local research where the time of year when a local pond would freeze (and then melt) to tie local knowledge of weather and climate patterns to larger climate trends. The simple analysis in Betts (2011b) shows a simple, clear trend toward later freezing and earlier melting of the local pond, which demonstrates a trend that is easily understandable by a community of nontechnical readers. By examining the observations further, he detects a trend of a decrease in the time that the pond is frozen of approximately 7 days per decade; this trend is then compared to the much more sophisticated projections from research climate models and is demonstrated that the results of the simple study broadly match the trends predicted by the model. In this manner, a context of understanding is developed and then applied to a larger, more complex result of climate science, maintaining a shared context throughout the process.

It is also possible to engage the public in the scientific process by creating a shared context through direct research involvement. Rogers and Vane (2009) present case studies of student scientific outreach where students, trained in observing cloud cover and identifying cloud type, begin to examine some of the properties of their local environment. In one case study, students in rural Thailand began by observing the amount and type of cloud cover through a school year – a relevantly simple process involving 10–15 min of instruction with a cloud chart. With this simple context in hand, the students moved on to observe changes in the local cloud cover (and the attendant rainfall) and began to tie these changes to observations of change in their local environment. One student group was able to observe a coincident change in the time of budburst (flowering) of a local tree with changes in the temperature and cloud cover in their region. Over the next few years, the students documented that budburst for this particular species of tree happened later each year, which they discovered was perhaps a consequence of increasing temperature in the region, which in turn was tied into changes in the cloud cover. Through the process of their research, the students were required to expand their knowledge set, from simply identifying cloud types, to understanding the impact of certain kinds of clouds on the local temperature, to ultimately understanding biological response of certain trees to stimulus from rainfall and temperature changes. By providing the students with a simple, shared context of looking at observations (identifying cloud type at a certain time,) the students were motivated to conduct research on local climate change due to atmospheric processes, resulting in scientific results (evidence of a biological response local climate change due to changes in atmospheric processes) that might not have been easily understood were the students simply presented with the results of the study first.

6 Discussion

Creating a shared context for understanding climate science through a data-centered approach addresses many of the issues facing scientists and educators attempting to disseminate scientific research in general. Specific research projects or results may present scientists and educators with challenges that may not respond well to a data-centered approach, and the technique cannot be thought of as a "cure all" for the very real problem of presenting complex scientific research to the public at large. For intentional education and outreach purposes, however, the approach has the benefit of creating a community between scientists engaged in education and outreach and educators, teachers, media, and members of the public through the process of exploring scientific concepts through exploring observations and, in doing so, helps to create shared context that helps to foster better communication of science results. Additionally, concerns of scientific integrity and impartiality may be assuaged on the part of the scientist by strictly holding to the principles of the scientific method as applied to the analysis of the observations.

The motivation for a data-centered approach is that by starting with the data, an interest in climate comes from internal motivation and shared context, and through exploration of the data, basic science concepts are better understood, which is hoped to foster an increased sophistication and ultimately a better understanding of scientific research of the Earth's climate.

Overview

Status Quo and/or Trends

– Scientists present a research based on a frame of relevance that is tied to the scientific process, including an implicit understanding of observations, uncertainties, and applicability and extent of the scientific results.
– The public understands climate science in the framework of relevance to social constructs and not necessarily the constructs used by scientists.

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– Assumptions about shared context and relevance made by climate scientists cannot be expected to hold when disseminating research results to the public.
– Misunderstanding and miscommunication of climate research results when differences in context and relevance are ignored.

Challenges to Overcome

– Understanding the special circumstances to each audience is required to understand the key relevancies and context that will facilitate good communication of research results.
– Finding a way to reframe scientific results to be understood in the appropriate context for an audience is difficult for the climate scientist.
– Engaging the public sphere with climate science research presents issues of integrity and impartiality to the climate scientist.

Recommendations for Good Practices

– Rely on collaboration and continued feedback between the climate scientist and audience specialists such as educators.
– Use scientific observations as a shared context for understanding scientific research, with appropriate scientific observations relevant to the target audience ensured by collaboration and communication.
– Explore scientific content and research results by looking at the observations using simplified, but accurate, scientific approaches.
– Maintain a common context and relevance between scientist and audience to expand basic comprehension of scientific data to more comprehensive understanding of the processes of climate science.

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Geoscience Outreach Education with the Local Community

Jennifer Saltzman

1 Introduction

On the grassy field beside the Geocorner Building at Stanford University, sixty 6-year-olds become an exploding volcano under the direction of a seismology graduate student. They huddle together as magma inside of the imaginary volcano and begin to move more quickly as they become hotter. At a certain point, they are moving fast enough that they explode and run around getting out the wiggles and imagining they are flowing down the side of the volcano. The young students are not typical Stanford visitors, yet have become a regular part of the learning community in Earth Sciences. This active learning game is the midmorning break of Geokids, a field trip for second-grade students to campus. Geokids is one of the many offerings from this research-intensive geosciences institution to share our understanding of Earth with our local community.

The School of Earth Sciences at Stanford University works to gain a better understanding of our planet's history and its future, the energy and resource base that supports society, geologic hazards that impact a growing population, a changing climate, and the challenge of sustainability. Within this scientific agenda, we have created opportunities to share this understanding with our local community of students and teachers. Our faculty and students want to reach beyond their colleagues and often don't have the time or expertise to commit to such endeavors. As the Director of Outreach Education, I have been fortunate to have the resources and encouragement to create opportunities within the school.

As with most outreach education, there are several driving factors even though it is not the central focus of a research university. First and foremost, outreach education is the right thing to do as individuals and for the university. Understanding Earth

J. Saltzman (✉)
School of Earth Sciences, Stanford University, Stanford, CA, USA
e-mail: saltzman@stanford.edu

V.C.H. Tong (ed.), *Geoscience Research and Outreach: Schools and Public Engagement*, Innovations in Science Education and Technology 21, DOI 10.1007/978-94-007-6943-4_18,

sciences is essential for solving many societal challenges today, and Earth sciences are not typically taught in school classrooms. We can help fill a gap and strengthen our local community's connection to Earth. Located in earthquake country, we have many experts who study the local hazards. Another driving force is to create relationships with our local community about our scientific research. Good community relations come from a personal connection between local citizens and the researchers at an institution. Funding is an obvious driver with the US National Science Foundation's Criterion II of Broader Impacts. Proposal evaluations include a review of teaching, training, and learning associated with the advancement of discovery and understanding (National Science Foundation 2011). Many researches ask for help with ideas, partners, and proposals because researchers know that contributing to primary and secondary education is one way to fulfill this requirement.

Having a dedicated staff member to run such programs creates an opportunity for many successes. While challenges may be abundant, the evidence of success contributes to the growth of the programs. This chapter will allow you to see how building on strengths and collaborations, being clear with expectations, and developing opportunities to support the research are essential for an education outreach program in a research-intensive geosciences institution.

2 Utilize Institution's Strengths

Outreach education comes in all shapes and sizes and depends on the people involved, audiences to be reached, and resources available. At a top-ranking, elite university, research is the focus, the archaic tenure system rules, and teaching beyond the traditional university students is limited. Yet our product is the intellectual power, the creative minds that bring about new understanding in Earth sciences as well as many other fields. It is the people – faculty and students – who are the real strength of the university. Successful outreach education programs need to connect scientists themselves, not just their results, to the outside audiences.

Not that a high school internship program is new or unique, it fits quite well with the strength of my university. High school students in California have little exposure to Earth sciences, yet many students yearn to help with science and are interested in environmental issues. For local high school students aged 14–18, we provide summer internships in an organized program that benefits the research community as well as the students. The interns work in the research labs where they get to handle samples, collect and use data, and get to know scientists while supporting ongoing research. We have come to realize that providing this type of experience helps the teenagers learn about what science really is and to contribute to science, while engaging and learning about one research project. The supervisors, typically graduate students and postdoctoral fellows, are also learning important skills of supervision and project management.

One rule for the interns is that they cannot only wash glassware. They are in the labs to learn about the science and contribute in meaningful ways. In the Paleobiology group, a team of 12 students over one summer plus a few interns for several other summers with calipers and 130 volumes of the Catalogue of Foraminifera, created a database of size and age for approximately 36,000 species of foraminifera. Researchers are using this database to identify environmental and ecological factors controlling evolution of body size over the past 500 million years. In other research groups, interns support dissertation projects such as by processing soil and water samples for carbon/nitrogen analysis or wavelet analysis of topographic data to image the morphological structure of the San Andreas Fault Zone. Several interns present their research at the AGU's annual fall meeting in San Francisco each year.

The interns not only get to learn about what goes on in their lab group but also are introduced to the wide field of Earth sciences on a weekly basis. Scientists and engineers talk about their research, show off their labs, and take the interns into the field. The interns meet a wide array of researchers in an informal setting where they are comfortable to ask all kinds of questions. Teenagers are being exposed to the strength of the university – the scientists – and are getting to learn firsthand from the experts.

3 Transparency in Expectations

On the Stanford campus, in the heart of Silicon Valley, everyone is busy and overcommitted. We all know what it takes to be a successful scientist, and outreach education is often not on the list. In outreach education, we depend on these super busy people to share their knowledge and passion with others. Most scientists love what they are doing and really do want to talk to people beyond their own field. They are passionate about their research and can talk ad nauseam about it for hours. (One night a good friend lectured for an extra 2 h on energy resources and the audience wanted more. The 2 h was in addition to the original 1-h talk.) These are the researchers that I want to connect with people beyond the university gates.

One of the audiences that is important to reach are teachers. In California, Earth sciences are highlighted in the sixth-grade science standards for 11–12-year-olds. Going back to the first point of taking advantage of strengths, we have developed a teacher professional development project that focuses on the sixth-grade science standards in California. Working with faculty and graduate students, we've developed modules to use with sixth-grade science teachers. The modules draw on the strength of the research that goes on here while teaching the basic principles of Earth sciences. By working together to develop the modules, my expectations became clear to the researchers. The scientists know that they can't just talk about what they are interested in, unless it fits into what the teachers need. Also, by preplanning from the first year and reusing and tweaking the modules each year, the scientists learn what is expected of them.

In planning other teacher professional development opportunities as well as the weekly sessions with the high school interns, clear expectations are essential. We have all sat through sessions where we are talked at and come away with nothing new. This often happens because the instructor did not spend the time to think about audience needs or best instructional practices. Lecturing can be an effective way, but not always and not with everyone. By communicating with the scientists before hand, they know the background and size of the audience and what the constraints are of the session. We talk about what techniques would be best and what we want the participants to understand. After 6 years at Stanford, I have a group of scientists who want to participate in the education outreach programs because they know and trust that I will support them and tell them what is needed.

4 Strong Collaborations

Funding agencies highly suggest and look for partnerships in their granting process, yet sometimes it is just a last-minute flurry of calls to find that "partner" before the proposal is due. In reality, true partners and collaborations are built on a sharing of strengths. Back to the first point again, the strength of Stanford's Earth Sciences is the people – the scientists and their students who are experts in understanding how the Earth works. This is only one part of a good teacher professional development. The other essential part when working with teachers is an expertise in education.

As with most universities, there is traditionally a strong divide between the disciplines, and scholars in one field may not have any interest in the connection between their field and another. Education scholars in particular are asked to support science research funded by NSF by providing the teacher professional development. This model doesn't often work very well, although it can provide funding for the science and support for teachers.

Strong collaborations may take time to develop, or a mutual interest in a research question and approach may bring partners together quickly. In Earth Sciences, we have one such strong collaboration that came together quickly and has grown strong with our shared goals. We are working with the Stanford Teacher Education Program (STEP) on climate change education. It is a true collaboration in every sense of the word. The two principal investigators are from Earth sciences and Education. We have regular meetings with scientists, science educators, education faculty, and experienced teachers/graduate students in science and math education. It was a team effort to develop a scientifically accurate, academically rigorous, and grade-appropriate curriculum. And the team effort continues with professional development for teachers as well as in the research on the student learning. The science members are learning from the education experts, and the education members are learning about the science and policy of climate change.

The journey to this successful partnership began at the grant writing stage. We already knew each other and quickly figured out that our goals were very well aligned and overlapping. We all brought different strengths to the project and were clear about our expectations and responsibilities. Once funded, the whole team came together to develop a shared vision of learning objectives for the teachers and students. The side benefit to this time was creating social connections within the team. Personal relationships within a disciplinary group can be beneficial and are just as important when working with people from other fields.

The collaboration creates a strong project for the teacher participants. They want to attend the training institutes and to implement the curriculum with their students. They work with the science and education experts to support student learning. Also, the project attracts teachers who are associated with STEP and introduces them to School of Earth Sciences and vice versa. The exchange of ideas comes from both the multidisciplinary project team and the diverse teachers who participate.

Not every program or effort requires partners and collaboration. It depends on the expertise needed to fulfill the goals. In most of the education outreach, the partners are the faculty and students who become the teachers and content experts. They fulfill a need and, with clear expectations, help serve to educate our local community.

5 Support Education and Research

Although it may seem obvious, outreach education can only be successful if it supports the goal of the institution. From museums to small NGOs to research universities, the central focus may not be outreach, yet outreach education helps serve the central mission. Outreach education includes working with teachers, students, and parents to reach people beyond the traditional student or visitor. Sometimes it includes businesses, governments, and the media to share the new knowledge that is created at the institution.

At a research-intensive university, cutting-edge research and training graduate students are the central goals. Funding is critical for both endeavors. The US National Science Foundation recognizes the value of sharing the newly created knowledge and the need to broaden participation and enhance diversity in science. The broader impacts criterion has infused NSF-funded research with opportunities in outreach education on one hand and has made outreach education services a plus for universities. At Stanford, outreach education is led by individual principle investigators or by science outreach specialists who work with larger projects to support individual or larger center projects. Having staff dedicated to outreach, a rarity in most academic institutions, shows the university's commitment and its understanding of the need for outreach education. The outreach staff, such as myself, know that the projects must support the central mission of the research and graduate training.

There are several programs that support research funding and graduate student training, by allowing faculty to plug into them with smaller grant proposals. Since 2003, we have run a campus field trip called Geokids for early elementary students (Saltzman and Paytan 2007). In Geokids, about 1,000 local students participate each year with morning field trip, taught by nearly 30 Stanford students. It is a chance for the university students and faculty to share their love of Earth sciences with the next generation, but more importantly, they practice their communication skills at the simplest level. This is a training opportunity for our students to become better educators and support the local community. Faculty can also take advantage of Geokids by including it in their funding proposals.

The high school internship program serves in supporting the mission of research and education as well. The interns contribute to ongoing research and the graduate students gain supervisory experience and management skills. The faculty include hosting high school interns in their funding proposals. The program infrastructure is set up already, and with the right project, it is a perfect fit for a high school student to work on a research grant. Many high school students from low-income homes must work during the summer. By providing funding from research grants, students can support their families and see that science research is a viable career. The funding provided by grants to support diverse student participation is vital to programs such as our high school internship program.

Overview

Status Quo and/or Trends

- The geosciences are more than just digging for dinosaurs or creating a rock collection. Through outreach education, universities can create opportunities to explain the different methods and evidence used to understand how the Earth works as well as encouraging study of rocks and fossils.
- With added opportunities, the rock hound can find like-minded people, as can the environmentally minded students who want to help reduce carbon emissions in the world.

Challenges to Overcome

- Faculty and students are very busy and often don't make the time for outreach. A community where outreach education is valued through participation takes time to create.
- Turning the strengths of an institution into outreach creates richer opportunities yet getting the support of the institution may take time and effort to develop.
- Outreach education must support research yet the connection between the two may not be apparent to researchers. Finding the overlaps in research and education, and translating the science for a less knowledgeable audience takes patience and teamwork.

Recommendations for Good Practice

- Outreach education programs can be successful when the programs support the institution's mission of research and education. This can help create institutional support which in turn helps create longevity of programs.

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– Defining the audiences or the subject matter to narrow what opportunities to offer helps limit and focus a program. No outreach program can do everything well.
– Transparency in expectations help create a community to support and deliver outreach education.
– Developing collaborations are a worthwhile investment when there is a shared vision.

Acknowledgments Thank you to the faculty and students at Stanford Earth Sciences who participate in the many outreach education programs. These ideas come from their continued support of the programs and me. I would also like to acknowledge my colleagues in education and other outreach programs across Stanford who also provide great support and insight into running education outreach at Stanford University.

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Using Research to Promote Action in Earth Science Professional Development for Teachers

Chris King

1 Introduction

Educational research has proved vital to the implementation and development of the Earth Science Education Unit (ESEU). Over the 12 years of its activity, the ESEU has presented Earth science Continuing Professional Development (CPD) workshops to more than 23,000 teachers across the UK.

The research firstly indicated the necessity of such initiative and then was used to evaluate the effectiveness of the strategies used and the success of the whole project. *Necessity* was shown by researching the background and practices of the science teachers teaching Earth science as part of the National Curriculum in England and Wales and in identifying the shortcomings of the Earth science content of examinations and syllabuses being used at the time. The *effectiveness* of the approach was shown through post-workshop feedback and by research into the impact of the workshops on teaching, which was undertaken a year after the workshops had been presented. The *success* of the project was indicated by the large numbers of teachers and trainee (pre-service) teachers who had participated in workshops and by the fact that ESEU is currently invited to present workshops annually at more than half the teacher education institutions in the UK.

Each key item of research is presented in historical sequence below, interspersed with the impacts they had on ESEU proposals and bids for funding from the ESEU sponsor, Oil & Gas UK, at the different stages. The learning from the research and ESEU developments is presented as guidance for others seeking to implement similar initiatives elsewhere.

C. King (✉)
Earth Science Education Unit, Keele University, Keele, UK
e-mail: c.j.h.king@keele.ac.uk

V.C.H. Tong (ed.), *Geoscience Research and Outreach: Schools and Public Engagement*, Innovations in Science Education and Technology 21, DOI 10.1007/978-94-007-6943-4_19,

2 Late 1990s

2.1 The Survey of Teachers

The National Curriculum for Science (NCS) was first implemented in England and Wales in 1989 and, for the first time, through its ‘broad, balanced science for all’ philosophy, required that all children in maintained (government) schools were taught Earth science as part of their science curriculum. The amount of Earth science in the curriculum for 11–16-year-olds was small, forming some 7 % of the whole science curriculum.

Ten years later, in the late 1990s, it seemed timely to review the progress of Earth science teaching as part of the curriculum. Thus, a questionnaire survey of teachers of Earth science was piloted. Following some post-pilot adjustments, the survey was circulated to science teachers of Earth science in the North West England, Northern Midlands, central Southern England and South Wales regions of the UK. Details of the survey and its findings from the 162 questionnaires received were published by King (2001) and revealed the following:

- The teachers had a variety of ages and years of teaching experience; 57 % were male and 43 % female.
- There were roughly equal numbers of biology, chemistry and physics specialists and very few teachers with a geology background.
- The amount of Earth science education the teachers had received as part of their own education is shown in Fig. 1, illustrating that nearly two thirds of the teachers had been taught no Earth science during their education, whilst most of the remainder had received only a little.
- Despite the low level of Earth science education received by most teachers, they viewed their background knowledge, on a 1–5 Likert scale, as *moderate*, as shown in Fig. 2. Indeed they regarded most elements of this part of the survey as *moderate*, their confidence and enjoyment in teaching Earth science (*moderate* to *high*), their views of the importance of the subject and the interest of the pupils (*moderate*) and the achievement of their pupils (*moderate* to *high*).
- The survey, however, revealed that the amount of practical work used in lessons was moderately low, whilst the amount of investigational practical work was very low (Fig. 3); this finding should be set against the high content of practical work in most UK science lessons (see Martin et al. 2008, p. 96). The term *practical work* is widely used in UK science teaching to indicate activities usually carried out by groups of pupils using apparatus in science education laboratories; meanwhile, the term *investigational practical work* implies that pupils have developed and carried out an investigational plan and have come to a conclusion and evaluated their work; in some situations, this is referred to as *inquiry-based science teaching*. The majority of teachers (83 %) surveyed indicated that they undertook no Earth science fieldwork.
- The teachers were asked to indicate the main sources of support they used for their Earth science teaching, and their response is shown in Fig. 4. Their main

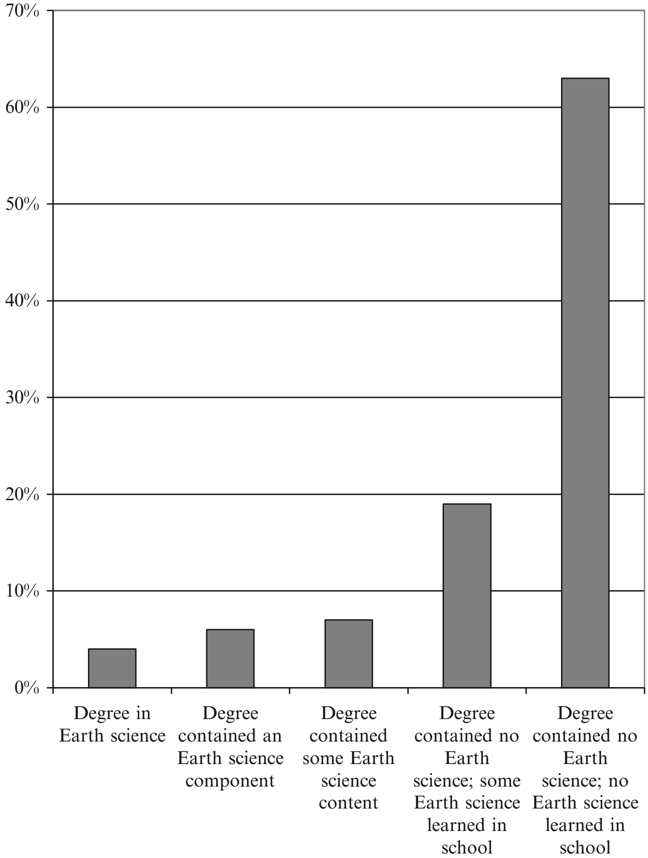

Fig. 1 The Earth science education of the teachers surveyed ($n = 162$)

source of support was science textbooks written for 11–14-year-olds (37 %), science texts for 14–16-year-olds (22 %) and general science textbooks (43 %). This finding related closely to the findings of the Council for Science and Technology (CST) at the time (CST 2000) that a high percentage (89 %) of secondary science teachers reported that they *often* used set textbooks. The second major source of support to the science teachers of Earth science was their colleagues (science teachers, 67 %, and geography teachers, 22 %); the CST (2000) report of a high dependence on advice from colleagues accords with these findings. The teachers reported that their use of specific Earth science/geology teaching materials was a good deal lower and that most (95 %) had undertaken no professional development in Earth science teaching.

These findings indicate that despite the *moderate* perceptions of the teachers of their Earth science teaching, the fact that their use of practical work was low, that their main source of support for their Earth science teaching was science textbooks

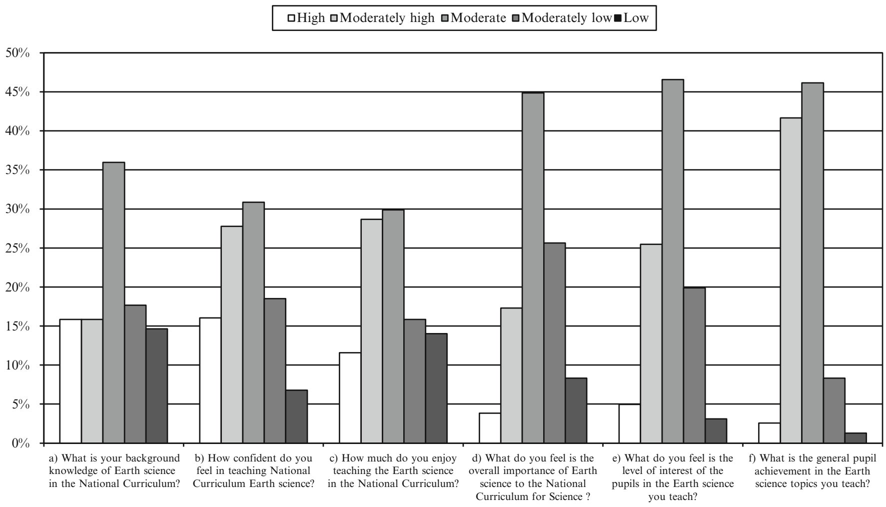

Fig. 2 Views of the teachers surveyed relating to (**a**) their background knowledge of National Curriculum for Science (NCS) Earth science, (**b**) their confidence, (**c**) their enjoyment, (**d**) the importance of the subject, (**e**) the level of pupil interest and (**f**) the level of pupil achievement in the Earth science area ($n = 162$)

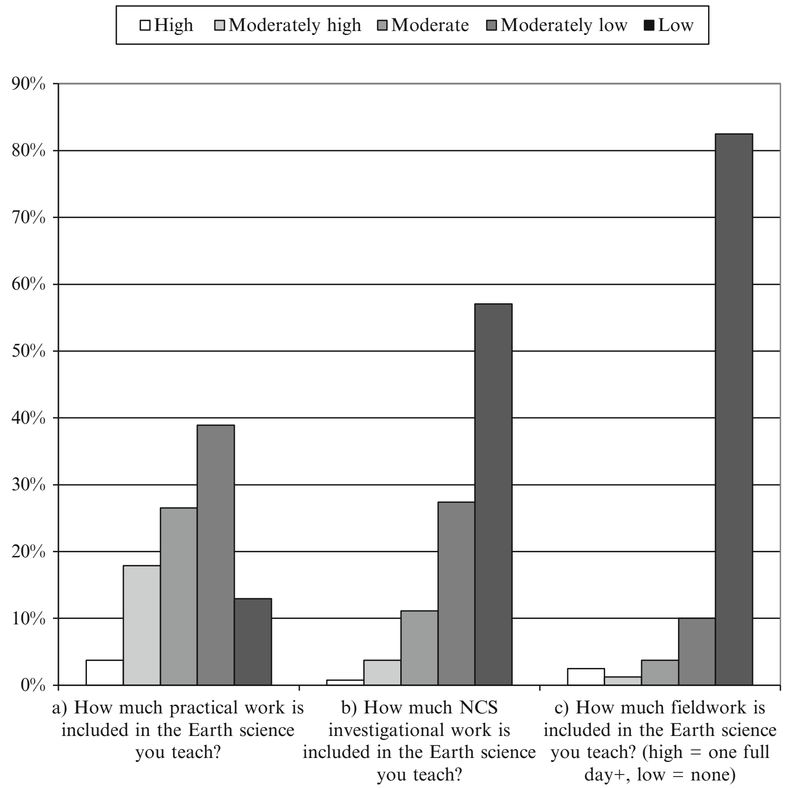

Fig. 3 Views of the teachers surveyed on the amount of (**a**) practical work, (**b**) investigational work and (**c**) fieldwork in the Earth science they were teaching ($n = 162$)

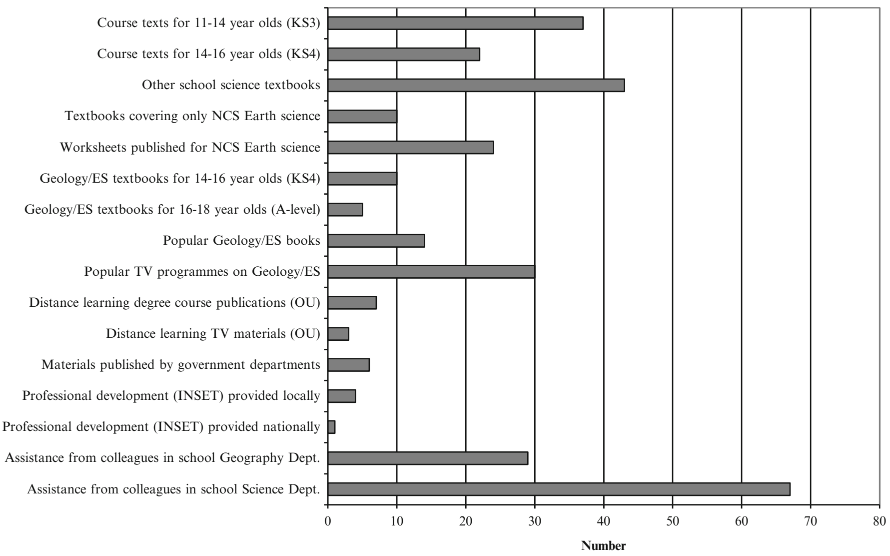

Fig. 4 Responses to the question: Which of the following have you found helpful in your Earth science teaching so far? ($n = 146$)

written for pupils and that they used their science colleagues as an important source of support (who may have had equally poor Earth science backgrounds) suggests that the quality of their Earth science teaching was poor. Indeed the findings were summarised in presentations to various audiences based on this survey as follows: *The Earth science taught is often poor*, *uninspired*, *dull and even wrong – through no fault of the teachers*, *who have never received training in Earth science*, with no disagreement by those present at the presentations.

The findings also showed that although Earth science materials specifically designed for the science curriculum were available and were used as the basis of professional development offered both locally and nationally, little use was being made of these resources by the teachers concerned.

2.2 *The Syllabus and Examination Survey*

The National Curriculum is assessed for 16-year-olds by the General Certificate in Secondary Education (GCSE) examination in England and Wales. This examination is provided by a number of independent Examination Boards (now called Awarding Bodies) which are independent of government, but are overseen by government organisations. In the late 1990s, the National Curriculum for Science Earth science content was assessed through *Double Award Science* GCSE examinations. In 1998, the syllabuses (now called specifications) of all the 11 *Double Award Science* examinations were evaluated for their coverage of the Earth science content of the National Curriculum for Science, whilst errors and oversimplifications were also recorded.

Each syllabus was evaluated independently by two of the evaluation team members against a proforma (standard reporting sheet), and the results were combined. The results were reported by King et al. (1998, 1999) and showed that of 22 National Curriculum statements relating to Earth science, a mean of 9.5 statements (range from 5 to 13) were inadequately covered or not covered at all whilst the syllabuses contained a mean error/oversimplification level of 2.6 per syllabus (range from 1 to 6).

A similar methodology was used to compare the examination papers set for candidates in 1996, for all 11 examinations, finding that a mean of 5 % of the exam marks were available for Earth science (range 8.7–1.9); the mean percentage of questions containing errors was 10 % (range 0–60 %); the mean percentage of low demand questions was 27 % (range 0–40 %); and the mean percentage of recall-only questions was 43 % (range 18–79 %). The latter finding should be set against the limit recommended by the government Qualifications and Curriculum Agency (QCA) which oversaw the examinations, of 20 % of recall questions.

In summary, these findings indicate that:

- No syllabuses had adequate coverage of the National Curriculum for Science with the worst covering less than half the statements adequately.
- No syllabuses were error free, with the worst containing six errors.
- Whilst most of the 11 examinations set in 1996 were error-free, three contained errors, one had 17 % errors, one had 18 % errors and the worst had errors in 60 % of the Earth science-related questions, i.e. more than half the questions were erroneous.
- The level of low-demand Earth science questions was high and the mean level of 43 % recall-only questions was more than double the recommended 20 % limit; the worst exam had 67 % of low-demand questions and 79 % of recall-only questions.

As a result, King et al. (1999) concluded, 'The serious issues identified have ramifications for a scientifically literate society needing breadth and balance in their scientific understanding. … many examiners are either choosing to interpret the statements in a minimalistic way or worse, probably as a consequence of their own lack of understanding' (p. 92).

The syllabus survey was repeated in 2004 (King et al. 2004) and 2007 (King and Hughes 2007, 2008) with improvement in coverage and reduction in error level, possibly caused by results of previous surveys being circulated to the Examination Boards/Awarding Bodies concerned.

2.3 Using Research to Promote Action I: The Earth Science Education Unit Pilot, 1999–2001

Following the teacher and the syllabus/examination research, an initiative was planned to offer Earth science education workshops to science teachers, using the teaching materials developed by the Earth Science Teachers' Association (ESTA), (see Kennett and King 1998 for a description of the materials). At the same time, the trade association of the UK offshore oil and gas industry (UKOOA – later

'Oil & Gas UK'), following concern about the future supply of geoscientists to the industry, was investigating the possibility of developing an initiative of their own to support education. They had initially planned to produce educational materials to assist science teachers with their teaching of Earth science, but the following evidence convinced them to take a different path:

- The evidence from King (2001) that science teachers of Earth science had poor Earth science backgrounds and produced Earth science teaching that was *poor*, *uninspired*, *dull and even wrong – through no fault of the teachers*, *who have never received training in Earth science*
- The evidence that the main source of support for these science teachers was science textbooks written for pupils (King 2001), which anecdotal evidence indicated were often poor and error prone (see Fisher 1992; Arthur 1996)
- The fact that ESTA had already produced a wide range of materials targeted at the National Curriculum for Science – but these were little used
- The fact that ESTA had offered workshops based on the materials, both locally and nationally – but these were poorly attended
- The research evidence (King 2001) that teachers of Earth science rarely used materials specifically produced for Earth science teaching or attended Earth science professional development workshops
- The evidence in the Council for Science and Technology (CST 2000) report that secondary (high school) science teachers rarely use materials produced by industry *frequently* (4 %) but use them only *occasionally* (37 %) or *never* (50 %) ($n=576$) – with equally poor results for publications by government (83 % *rarely* or *never*), societies (88 % *rarely* or *never*) and museums (90 % *rarely* or *never*)

For these reasons, UKOOA decided to support the initiative to take Earth science workshops, based on ESTA practical activities, to science departments in schools free of charge, based on the philosophy that *if teachers won't go to Earth science CPD workshops*, *you have to take the workshops to the teachers*. To do this, the Earth Science Education Unit (ESEU) was formed, based at Keele University, and two experienced teachers were appointed part-time to support the programme. This allowed workshops to be offered in the Yorkshire area, North West England and the Northern Midlands. The workshops were deliberately designed to be short (90 min), with the duration being chosen as a pay-off between the amount of time teachers would be willing to spend on an Earth science workshop and the time and expense of a workshop presenter travelling to a school, setting up and presenting a workshop. The short workshops were either offered in a twilight session or combined into half-day or full-day sessions.

Over the first 2 years of ESEU activities (1999–2001), 100 visits were made to 47 school departments and 16 teacher education establishments, with ESEU workshops being presented to 763 teachers and 539 trainee (pre-service) teachers. Each participant was asked to rank the workshop in four categories on a 1–5 Likert scale (1 = high), with the following responses: 'effectiveness', 1.48; 'interest', 1.42; 'relevance', 1.45 and 'value', 1.51, with many positive written comments. In view of the later ESEU progress, this phase was retrospectively called the *ESEU pilot*.

3 Early 2000s

3.1 The Teacher Misconceptions Survey

Participants in some of the early ESEU *Plate Tectonics Interactive* workshops were asked before the workshop to complete a sheet asking them to label and draw diagrams related to the content of the workshop ($n = 61$). The results of their efforts are shown in Fig. 5 and reported in King (2000).

The graph shows that:

- nearly half the teachers asked had no real concept of the scale of the crust relative to the whole Earth …
- a third of the teachers had little idea of how 'S' wave velocity changed with depth …
- three quarters of the teachers did not appreciate how the supercontinent Pangaea … [can] be reconstructed …
- half the teachers did not appreciate how earthquake depth evidence can be used to support plate tectonic theory;
- a quarter of teachers did not appreciate the importance of the heat flow evidence;
- most teachers had wrong ideas about the state of the different Earth spheres, and
- nearly a third of teachers did not apply physical principles to an understanding of the density of the Earth. (King 2000, p. 61)

This phase of the research concluded, '… it is of great concern that so many teachers made bad errors in answering [the questions] … the term 'badly wrong' [in Fig. 5] means that the answer given contained at least two errors and showed major misunderstanding of the factors involved' (ibid, p. 61).

A limited number of the teachers involved were asked to complete the sheet again after the workshop, and a marked improvement in response to the majority of the questions was noted. This provided valuable evidence of the effectiveness of the ESEU professional development approach.

3.2 Using Research to Promote Action II: The ESEU National Roll-Out, 2001–2006

The results of the ESEU pilot evaluations, together with the evidence of the impact of the workshop from the plate tectonic misconceptions survey, were used as part of the bid for further funding from UKOOA. The new proposal submitted was for a national roll-out across the UK over the five following years. Since the pilot had shown that the strategy of employing part-time workshop presenters was not sustainable across the whole country (being expensive and inflexible; the inflexibility

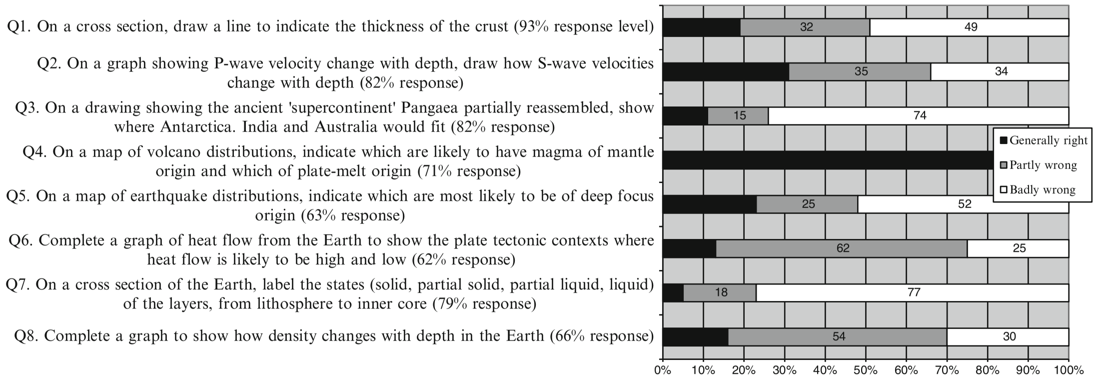

Fig. 5 Teachers' responses to questions on plate tectonics and the structure of the Earth, before receiving Earth science professional development (the percentage of the 76 teachers who responded to each question is shown in *brackets*)

deriving from the availability of part-time presenters, who often were not available at the times when they were wanted by schools), a new business case was developed with the support of UKOOA of appointing a network of facilitators (workshop presenters) who were asked to present workshops on an *ad hoc* basis. In this way, the facilitators were only remunerated for workshops they presented and were not paid during any 'downtime'.

Because of the compelling evidence for the continued necessity of ESEU activity, its effectiveness and its impact, described above, the bid was successful. Funding was received to roll workshops out across the country progressively from 2001 to 2006. Facilitators were advertised for, interviewed, appointed and trained in workshop delivery and in the educational and Earth science backgrounds behind each workshop; first 14 facilitators were appointed, rising to 29, and then to 35 in 2005.

The educational system in Scotland is very different from that in England and Wales, with the primary/secondary transition taking place a year later in Scotland and different curriculum and examination systems. The majority of the Earth science content in Scotland appears in the upper primary (elementary) curriculum. Thus, the roll-out across Scotland, which began in 2003, involved developing and piloting two workshops aimed at the upper primary curriculum. These were devised by a collaboration between the ESEU, Scottish Earth Science Education Forum (SESEF) representatives and local primary teachers. Eight Scottish ESEU facilitators were appointed and trained, allowing the workshops to be offered across Scotland.

Between 2001 and 2006, ESEU presented workshops to more than 3,300 secondary teachers and 3,900 trainee teachers in England and Wales, with the high level of positive feedback recorded for the pilot being maintained. Meanwhile, ESEU workshops were presented to more than 1,300 primary teachers and trainee teachers across Scotland, with equally positive feedback.

3.3 Using Research to Promote Action III: The Joint Earth Science Education Initiative

The research findings were also used to make the case to representatives of the Royal Society, the Institute of Biology, the Institute of Physics and the Royal Society of Chemistry, supported by the Geological Society, the Earth Science Teachers' Association and UKOOA, for the development of Earth science materials specifically aimed at biology, chemistry and physics teachers. This was the first time that these institutions had worked together to develop educational activities in this way. The activities were developed at a writing workshop attended by education officers and teachers nominated by each organisation. Thus, the Earth science educational activities were specially written *by biology teachers for biology teachers*, *by chemistry teachers for chemistry teachers and by physics teachers for physics teachers*. The Earth Science Education Unit facilitated the workshop and the activities were published on the Joint Earth Science Education Initiative website (JESEI Website). The 40 activities developed and published used a wide variety of approaches appropriate for secondary science teaching and were well received.

3.4 The Textbook Survey

There is no government control of textbook quality in the UK and anecdotal evidence (Fisher 1992; Arthur 1996) had suggested that the Earth science content of secondary science textbooks in the UK was poor. Meanwhile, research evidence had showed (CST 2000; King 2001) that science textbooks were widely used by secondary science teachers. Thus, it seemed beholden on the Earth science education community to conduct a survey of the quality of the books being used.

As a result, a team of five experienced Earth science educators surveyed all the science textbooks being used in schools in England, which were in print, in 2002. The survey covered 13 textbooks/series from 10 publishers at Key Stage 3 (KS3, 11–14-year-olds) and 16 textbooks/series from 9 publishers at Key Stage 4 (KS4, 14–16-year-olds), a total of 51 texts. A proforma (standard reporting sheet) was developed against which each textbook or series could be evaluated, based on the proforma used for the previous syllabus survey (King et al. 1998) and covering all the Earth science-related statements in the National Curriculum for Science (NSC), subdivided into 17 statements at KS3 and 22 statements at KS4. A moderation (review) exercise was undertaken by asking all the evaluators to evaluate the same textbook and agree a standard response. Then each textbook was evaluated for extent of coverage against each of the statements, and the result recorded as *comprehensive* (going beyond the coverage implied by the NSC statement), *basic* (meeting the coverage implied), *less than basic* (not meeting the coverage implied) and *none* (no coverage could be found in the obvious places in the textbook or through the index). The percentage of each book given over to Earth science was recorded (number of Earth science pages against the length of the book), together with the number of *errors/oversimplifications* and the *extras*, the material included beyond the National Curriculum requirements. The proforma evaluations were submitted to the team leader who moderated them against one another, carried out the analysis and compiled them ready for publication.

The results were published in an internal report which was circulated in draft form to all the publishers involved, modified in response to their (limited) comments and then recirculated as a final report (King et al. 2002). The findings were also published (King et al. 2003, 2005).

The survey found that on average, half the NCS Earth science statements were inadequately covered (8.8 of the 17 statements at KS3, ranging from 1 to 13; 12.5 of the 22 statements at KS4, ranging from 1 to 16), that it was the geological statements that were particularly poorly covered and that in the poorest textbooks, nearly the whole of the Earth science component of the NCS was inadequately covered or was missing completely. This is despite the fact that the percentage of Earth science content averaged

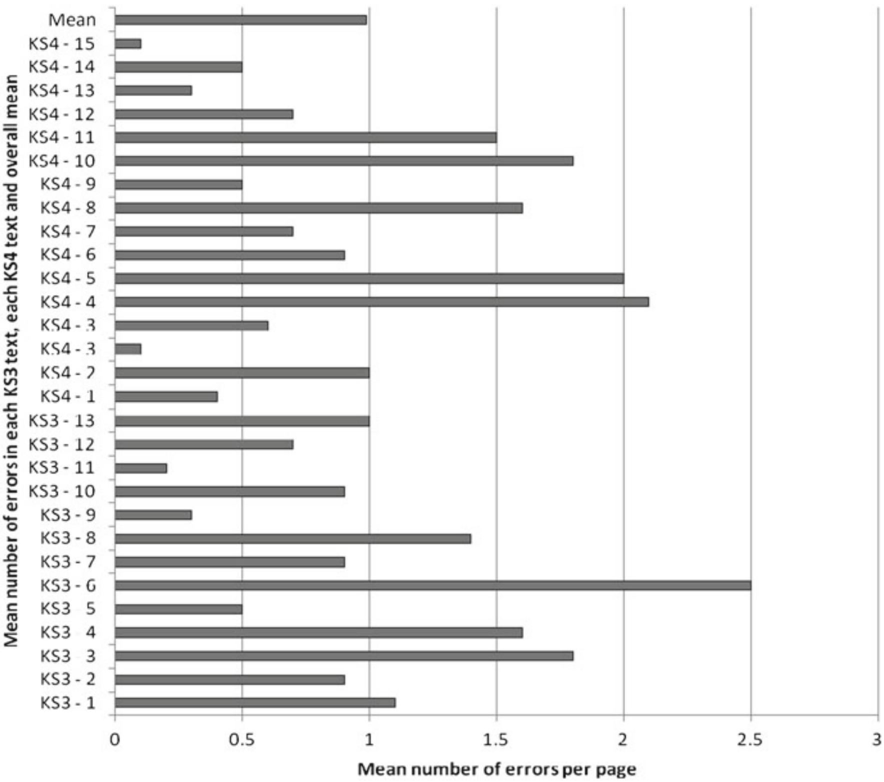

Fig. 6 Levels of error/misconception in the KS3 texts/series (for 11–14-year-olds, $n = 13$) and the KS4 text/series (for 14–16-year-olds, $n = 15$) reviewed, together with the mean error level

across all the textbooks, of 9.4 % (range 3.8–12.0 %), was high, when set against the percentage of Earth science in the NCS (as measured by the numbers of Earth science-related statements against the statements of other areas of science) of around 7 %. There was a mean of 7.3 '*extras*' (range from 1 to 16) across the textbooks.

The level of error/oversimplification was high, as shown in Fig. 6, and averaged one error per page (with the poorest example having 66 errors in 26 pages).

The survey had vindicated the wording of the title of Arthur's (1996) paper of *Lies*, *damn lies and books on geology* by revealing high levels of inadequate coverage accompanied by high mean error levels. Some textbooks had much better coverage than others, whilst the poorest examples were very poor indeed. For each *error/oversimplification* found, the sentence containing the issue was rewritten using a similar level of language and a similar number of words, and these rewritings were included in the report sent to publishers. This was done in order to illustrate that the Earth science could have been given correctly and to help the authors of future textbooks to improve their work. Some publishers responded to the final report by asking for advice on the Earth science content of books currently in development, but most did not respond.

The 453 examples of error/oversimplification identified were later further analysed, as described in '*The textbook misconception survey*' below.

3.5 *The CPD Impact Research: Mid-2000s*

Whilst many organisations offering Continuing Professional Development (CPD) workshops and courses collect evaluation evidence which shows that they were well received on the day, as was the case for ESEU workshops, most research into the impact of CPD on teaching and learning had focussed on long courses mainly provided in the USA. This research had come to the widely publicised conclusion that long-duration, well-supported courses did have impact in the classroom, whilst short courses were ineffective, as summarised by Adey (2004): 'There is universal condemnation in the research literature on professional development for the one-shot 'INSET day' as a method of bringing about any real change in teaching practice' (Adey 2004, p. 161).

ESEU therefore considered that it was crucial to discover whether or not ESEU workshops had impact, beyond the positive evaluations collected on the day of the workshop.

ESEU conducted this research by contacting all the 46 schools visited in 2003/2004, a year after the workshop had been delivered, and inviting them to complete a questionnaire concerning the impact of the workshop. The time interval of *a year after the workshop had been delivered* was chosen to give time for the school to work through its annual curriculum and for changes to be incorporated into their Earth science teaching. The 15 responses received (33 % response rate) indicated that all the schools which had Schemes of Work (the internal syllabus that schools in the UK work to) had adapted their Scheme of Work to incorporate ESEU practical activities with the numbers of practical activities included ranging from *significant* (seven instances), through *moderate* (four instances) to *modest* (a further seven instances). Since Schemes of Work, once developed, have longevity in the school curriculum, this was evidence of long-term change as a result of the ESEU intervention. The Lydon and King (2009) report on the research concluded the following:

> The demonstrated success of the ESEU model of short, single workshops in bringing about lasting change in practice is noteworthy, given the emphasis in the literature that CPD can only be effective if it is sustained. Interestingly, in his dismissal of the short CPD episode, Adey offered a case for exception:
>
>> There is universal condemnation in the research literature on professional development for the one-shot 'INSET day' as a method of bringing about any real change in teaching practice. Perhaps the only exception to this rule is the introduction of a very specific technical skill, such as the use of new piece of software. (Adey 2004, p. 161)
>
> The evidence described above indicates that this exception should be extended to include the transmission of practical science teaching ideas (and fostering of skills and confidence in using them, with the associated building of knowledge and understanding), where training is delivered by a well-trained provider, within a well-structured workshop which provides opportunities for exploration, practice, and peer feedback (Lydon and King 2009, p. 81).

The success of the ESEU in causing science departments to change their schemes of work to include ESEU activities, and therefore to provide practically based Earth science teaching to pupils in the succeeding years, may be due to a number of factors including:

- The poor Earth science education of the teachers prior to the workshop
- Their lack of awareness of a range of Earth science activities which had been shown elsewhere to motivate and engage pupils
- The enthusiasm and strong Earth science and educational backgrounds and the effective training of workshop presenters
- The use of a ‘circus of activities’ in most workshops through which participants have to report back to their peers, giving a second-hand ‘hands on’ approach to the activities
- The use of introductory and plenary activities intended to sum up the workshop for participants
- The use of materials and apparatus freely available in school science departments, allowing the activities to be easily replicated
- The fact that workshops are presented to whole departments, so that teachers can discuss the activities and support one another following the workshop
- The comprehensive written supporting and presentational materials provided to teachers at the workshop

4 Late 2000s

4.1 Using Research to Promote Action IV: The ESEU Consolidation, 2007–2011

In 2006, towards the end of the ESEU national roll-out, a further proposal was submitted to the oil industry sponsor (UKOOA, by now renamed ‘Oil & Gas UK’) for a further 5 year’s funding to consolidate ESEU’s national progress. A key part of developing the bid was to invite the Chief Executive of Oil & Gas UK to visit the ESEU at Keele so that he could be apprised of the progress so far. When the research findings underpinning ESEU were presented to him, in particular the poor backgrounds of teachers teaching Earth science, their reliance on science textbooks which had been shown to be of poor quality, the lack of use by teachers of materials produced by industry, government, etc. and the ESEU statistics so far, he responded in paraphrase: *But do we know that the ESEU makes a difference*? When ESEU was able to use the research evidence above to show that unlike many educational initiatives in the UK, the ESEU was demonstrably making an impact on classroom teaching, he was impressed and later responded, in paraphrase: *We must ensure this little gem is supported in the future*.

As a result of the visit, and the research-based bid submitted to Oil & Gas UK, a further 5 years funding was forthcoming, with the remit to maintain all existing activities and to extend the ESEU offer to primary (elementary) teachers in England and Wales.

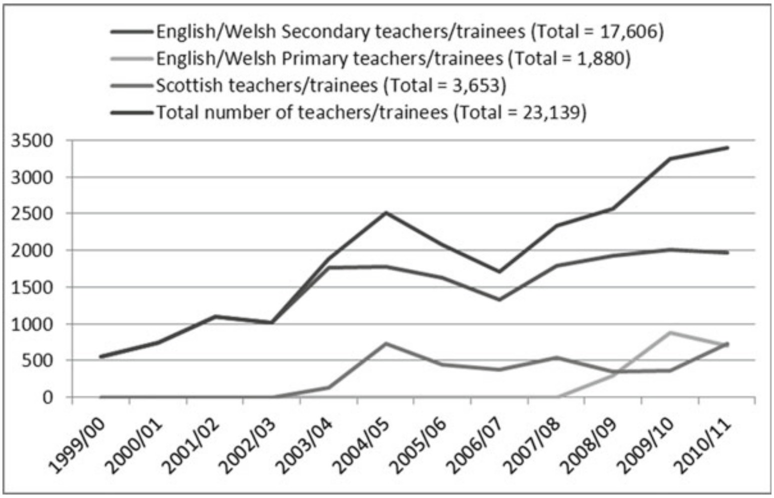

Fig. 7 The total number of individual teachers and trainees who received ESEU workshops, 1999–2011

During 2007–2011, ESEU not only developed and implemented primary workshops in England and Wales, it also comprehensively revised all its Scottish workshops to fit the new Scottish *Curriculum for Excellence*, developed a Scottish secondary-level workshop, revised the workshops offered in England and Wales, developed and implemented workshops in Northern Ireland and developed and rolled out a series of *Earth Physics* workshops to teachers of physics syllabuses to 14–18-year-olds.

Between 2007 and 2011, ESEU visited 386 secondary science institutions in England, Wales and Northern Ireland, presenting workshops to 1,184 teachers and 7,598 trainees. ESEU also visited 29 primary schools and teacher education colleges, giving workshops to 693 teachers and 1,163 trainees. Meanwhile, in Scotland, ESEU paid visits to 73 institutions, presenting workshops to 1,858 teachers and 483 trainees.

Over the full 12 years of ESEU operations, the figures show that ESEU has presented workshops to more than 23,000 individual teachers and trainees, who, between them, teach several million pupils (Fig. 7). Post-workshop evaluation feedback has remained very positive throughout. ESEU is now regularly presenting workshops at more than half the secondary teacher education institutions in the country (Lock et al. 2011a, b), and the number of trainees reached by ESEU has shown a steady increase year-on-year over recent years.

4.2 The Textbook Misconception Survey

The 453 instances of *error/oversimplification* found in the textbook survey (King et al. 2002) were added to the 20 instances previously recorded in the syllabus and examination survey (King et al. 1998), and a further 58 instances of *error/oversimplification*

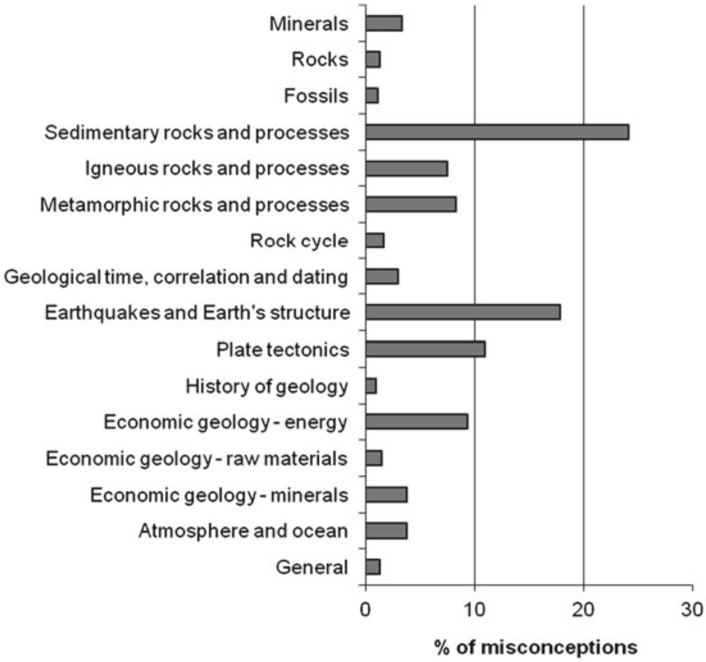

Fig. 8 Instances of *error/oversimplification* appearing in science-based published materials for 11–16-year-olds ($n = 531$)

identified during 2003 (38 from proofreading of prepublication science textbook material and 20 from a BBC science-revision website). The total number of 531 instances of *error/oversimplification* was then analysed as a guide to the areas of Earth science most prone to misconception. These are shown in Fig. 8, whilst the *top 15* misconceptions are graphed in Fig. 9.

The results and analysis were compared with the literature on misconceptions in Earth science, showing similarities with the misconceptions identified in secondary-level students, university students and trainee teachers, particularly in the USA, but in other parts of the world too. The analysis was published, together with guidance to authors on how to address the misconceptions in their writing, by King (2010a). This work on textbooks and the misconceptions they contained will hopefully be used by textbook writers in the future to produce much higher quality and accurate materials.

4.3 The CPD Impact Research: Part II (Late 2000s)

The CPD impact research carried out by ESEU in 2003/2004 was repeated for schools visited in 2007/2008. Questionnaire feedback using identical questions was received from 10 of the 32 schools visited, a 31 % response rate. Analysis of the data

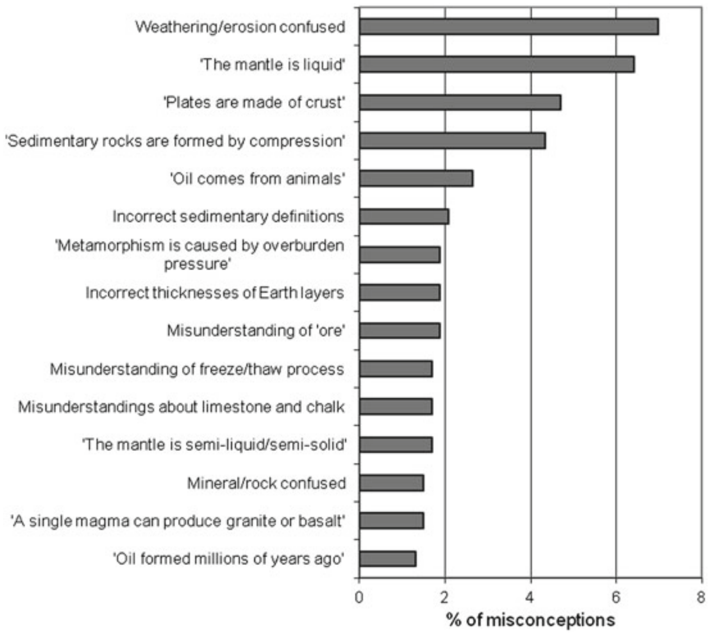

Fig. 9 The *top 15* misconceptions, graphed according to their contribution to the data ($n = 531$)

showed that most schools again had modified their Schemes of Work following the ESEU visit. The data also showed that more Earth science activities were being used in the school prior to the visit than was the case for 2003/2004. This may reflect the work of ESEU with teacher education institutions across the country, indicating that there is a better baseline of Earth science educational understanding as a result of ESEU efforts. Since the baseline was better, it was not possible for ESEU visits to cause the *significant* level of change found in 2003/2004. Nevertheless, four schools recorded a *moderate* increase in usage of ESEU activities, and eight recorded a *modest* increase with no school, of those which responded to the research, indicating that their teaching had not changed. This is despite the fact that in nearly all cases, the science departments had only received one 90-min ESEU workshop, and there was no opportunity for ESEU to revisit them at a later date.

As noted for the 2003/2004 survey, there were potential sources of bias in both surveys: 'The schools in … [these surveys] were self-selecting on two levels, having initially requested an ESEU workshop, and subsequently having chosen to respond to the survey. Thus these schools may represent: those who are more open to science CPD opportunities in general; those who have recognised a need for additional support in teaching Earth science; those schools for which an ESEU workshop had a noticeable positive impact; those most desperate for free resources [provided as an inducement to take part in the survey]; or (more likely), a combination of all of the above. This potential bias within the data must be borne in mind in generalising from the findings of the survey' (Lydon and King 2009, p. 75).

Nevertheless, the two surveys of impact together indicate that the ESEU short courses continue to have a positive impact on teaching in schools.

5 The Future

5.1 Using Research to Promote Action V: The ESEU Future

The research carried out around the activities of the Earth Science Education Unit has provided an evidence-based platform for the ESEU initiative to be maintained in the long term. With this in mind, an interim 1-year bid to the Oil & Gas UK sponsor was submitted in 2011, whilst a larger 5-year proposal for sponsorship and development was prepared to ensure that ESEU has the wider financial stability of funding and support being provided by more than one sponsor. The bid to Oil & Gas UK for a further 1 year of interim funding was successful, allowing ESEU activities to be maintained through 2012. Meanwhile, the broader bid for funding is being developed, in which the evidence base for the necessity, effectiveness and success of ESEU remain crucial.

In the new *five-year plan*, ESEU will expand its remit at Keele University to embrace the education of new geology teachers, through maintaining the current geology teacher training route at Keele University whilst developing summer school professional development courses for practising teachers of science and geography who want to extend their capacity to include post-16 geology teaching. ESEU also plans to develop its portfolio of workshops to include a workshop for special schools (for those pupils with disability), a new upper primary *Curriculum for Excellence* workshop for Scotland and a workshop on providing sustainable energy, including carbon capture technology.

The development of the ESEU initiative could not have taken place without the partnership of the offshore oil industry trade association, Oil & Gas UK, which has provided funding and a crucial business perspective, without requiring any emphasis on oil and gas or on the oil and gas industry during the ESEU work with schools, colleges and universities. There appear to be no published records of any similar industry/education initiative anywhere else in the world, where professional development is provided free of charge to schools through a network of facilitators without any overt *industry agenda*. The only agenda of Oil & Gas UK has been to improve Earth science education nationally, in order to increase the uptake of geology undergraduate education and the provision of future geologists and geophysicists.

So, the partnership of industry has been crucial in providing sponsorship and a critical business perspective – as has the research which has underpinned all ESEU activities. The research has shown the scale of the issues involved, has indicated strategies for addressing these issues most effectively and has shown the positive impact of the strategies.

5.2 *Using Research to Promote Action VI: Pointers for International Initiatives*

ESEU's research has allowed the development of a range of pointers for those considering implementing similar initiatives in other countries. These are based on ESEU's experience of taking an initiative from one country and implementing it successfully in another, in ESEU's case, from England to Scotland. Whilst it might not be apparent to those beyond the UK, the educational systems of the two countries are very different, with the primary/secondary transition taking place a year later in Scotland, completely different national curricula and school examination systems, and different university systems as well.

The factors likely to be necessary for success, based on ESEU's experience, are given in Box 1.

Box 1

To successfully launch a workshop-based educational initiative, like that of the ESEU, in a new jurisdiction, the following aspects appear to be critical:

Leadership

- An enthusiastic leader or team, with understanding of the issues involved, is needed to lead the initiative.

National Curriculum/Standards

- The content of the workshops must be part of the national curriculum or national standards.

Workshop Activities

- Suitable activities must be available, for use in devising workshops.
- The workshop activities should be hands on, interactive and capable of being implemented easily in schools.

Workshop Development

- Teachers and educators in the jurisdiction concerned must be involved in utilising the available activities and developing new activities to be incorporated into workshops that are motivating, flexible and appropriate for the educational situation in the jurisdiction.
- The activities should be incorporated into well-presented written materials with teacher guidance.

Workshop Presentation

- Because of the 'gearing' involved, it is much more efficient to present workshops to teachers than to pupils.

(continued)

(continued)

- Similarly, it is more efficient to present workshops to trainee (pre-service) teachers than to practising teachers, since trainees will generally teach for longer than practising teachers and, by visiting the same institutions annually, a new group of trainees can receive the workshops each year.

Industry/Education Partnership

- Significant and sustained funding is required to develop professional development workshops and to take them free of charge to schools and teacher training institutions; this allows a network of workshop presenters to be identified, trained and paid to take the workshops to the institutions concerned.
- The *business case* must be prepared, monitored and frequently reviewed.

Research and Evaluation

- Effective methods of evaluation and research should be in place during all stages of the initiative so that success and impact can be demonstrated to all the parties involved.

Preparation and presentation of teaching activities, as noted in Box 1, have been addressed by the publication of many of the ESEU activities on a website, so that they are free to download and use in any educational situation (The Earthlearningidea Website). By February 2011, 125 activities had been published on the website, many suitable for use in the developing world and in classrooms with few resources, with an additional activity being added every 2 weeks. On average, nearly 20,000 pdfs were downloaded per month during 2011, with more than half a million downloads since the inception of Earthlearningidea in 2007. The activities had been translated into Chinese (Mandarin), German, Italian, Norwegian, Portuguese, Spanish and Tamil (King et al. 2013).

Meanwhile, the Earth science educational research underpinning the work of the ESEU and its related activities has been published and presented at conferences, allowing others to use the findings to review Earth science education in their own situations (e.g. King 2008, 2009, 2010b, 2011). The published materials may also allow others to implement initiatives similar to that of ESEU in their own jurisdictions. In these ways, others may be encouraged to use research to promote action.

Overview

Background and Motivation

– Prior to the Earth Science Education Unit (ESEU), research into the effectiveness of the teaching the Earth science component of the National Curriculum for Science in England and Wales indicated that practice was poor.
– The ESEU initiative was therefore developed to address these issues through an industry/education partnership.
– It was vital to maintain research and evaluation strategies throughout the development of the ESEU to monitor the effectiveness and success of the initiative and to publicise the findings to those directly involved, to the sponsors and to the wider educational community.

Innovations and Findings

– The development of the ESEU as an industry/education partnership, with its underpinning research and evaluation, has proved to be a unique innovation, since no similar programme has been identified elsewhere in the world.
– The findings of ESEU research and evaluation continue to show that ESEU is successful (ref. the high positive levels of post-workshop evaluations and the ESEU research indicating that workshops had caused change in teaching in all the schools visited which responded to the research (32 %)).

Implications for Wider Practice

– The ESEU innovation has proved effective and successful across the UK according to all the measures applied; therefore, its current strategies should be maintained for the foreseeable future.
– ESEU's remit should be widened to include the recently identified necessity to support the development of geology teachers in the UK (previously, ESEU has only focussed on providing Earth science education to broad science teachers).
– ESEU's methodology for taking an educational initiative from one country and implementing a similar approach successfully in another (England to Scotland) has been described to enable others to undertake similar initiatives in their own jurisdictions.

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