Innovations in Science Education and Technology 20

Vincent C.H. Tong *Editor*

Geoscience Research and Education

Teaching at Universities

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University of London — Vincent C.H. Tong

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From Research-Implicit to Research-Enhanced Teaching: A Geoscience Perspective

Vincent C.H. Tong

The relationship between research and teaching has long been the subject of an ideological debate in higher education. As two of the most recognised functions of universities, how research and teaching are developed and valued varies significantly between institutions. Differences in institutional approaches reflect not only the influence of local factors such as missions, leadership and resources available but also the effects of national educational policies as well as evolving global trends in higher education. Despite these differences, it is not uncommon for universities with contrasting levels of intensity in academic research all showing their commitment to the research-teaching nexus. Studying how faculty and teaching staff bring research and teaching together is important for locating where this nexus is actually rooted. These investigations are also useful in providing evidence for developing and improving synergy between research and teaching. Apart from having philosophical discussions and institutional commitments with regard to the research-teaching nexus, the importance of understanding how it is enacted in practice cannot be overstated.

The case for forging links between research and teaching is strong. In fact, research and teaching are so intricately linked that their synergy may be discussed only in relative terms. Research may be regarded as an integral part of university education, and this is particularly evident when one considers the benchmarks of academic qualifications, including the specifications that form part of the Bologna Process in the European Higher Education Area[1] and similar standards used in other parts of the world. Under these frameworks, research-related competences are required for undergraduate studies, particularly at advanced levels, and become a definitive characteristic for higher degrees. In other words, these requirements stipulate that the boundary separating research and education is increasingly blurred for

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more advanced qualifications and undergraduate studies essentially represent a stage where such transition takes place. On the one hand, it may be difficult to imagine how university teaching, both at undergraduate and postgraduate levels, can be carried out without using any research materials or developing any research and inquiry skills. In other words, 'research' already exists in many, if not all, academics' teaching, albeit not necessarily in an explicit way. On the other hand, 'in-house training' through the teaching of research skills to undergraduate students is an effective, if not a necessary, way to sustain and develop the research capability of the higher education sector as a whole, which of course includes both research-intensive institutions as well as universities that are teaching-led.

Whilst 'research-enhanced teaching' is a much more commonly encountered concept than 'teaching-enhanced research', such asymmetry may simply reflect differences in purposes, objectives and relative priorities. Given the complex symbiosis between research and teaching, identifying where research skills and contents have been and may be introduced in one's teaching is crucial. Successful promotion of research-enhanced teaching ultimately depends on faculty and teaching staff reflecting on and recognising the relevance of the research-teaching nexus in their own teaching contexts. Any perceived dichotomy in the functions of research and teaching in universities may be viewed differently by faculty and teaching staff if elements of research in university teaching are made explicit. The necessity to nurture the next generation of researchers at undergraduate levels, particularly in the case of research-intensive universities, and to equip students with the inquiry skills for future employment makes the case for closer links between research and teaching ever more compelling.

As an approach to improve teaching quality, research-enhanced teaching is essentially voluntary and is rarely made compulsory. It is either initiated by the teaching and faculty staff themselves or is encouraged by initiatives at institutional or national levels. If research-enhanced teaching is to be adopted more widely and more effectively, it is useful to understand the perspectives of those who teach as well as those who are taught this way. It is particularly helpful to identify the challenges they face and the benefits the teaching approach brings. This is important because their perspectives are likely to be multifaceted, which may be associated with the differences in emphasis and priorities given to teaching and research at institutional and personal levels. Why do teaching and faculty staff value the research-teaching nexus? How do they perceive conflicts between research and teaching, if any? Apart from their perspectives, it is also helpful to understand the approaches adopted in research-enhanced teaching. After all, students and other stakeholders, such as employers, are directly affected by the ways of how research materials and skills are taught in universities. How do academics apply innovative approaches involving technology and other pedagogical designs in teaching geoscience research? How do they evaluate their teaching approaches? How do they teach university students at different stages of their studies? How can research-enhanced teaching be best supported at departmental and institutional levels?

In order to answer these questions, it may be useful to focus on a discipline and compare how research-enhanced teaching is implemented and evaluated. These investigations broadly fall within what is known as 'disciplinary-based education research', which has received significant attention as evidenced by a comprehensive study funded by the National Science Foundation in the USA.[2] Examples of how research-implicit teaching has been made explicit and enhanced within academic disciplines are reported in discipline-based education research journals and can be found in virtually all subject areas. Amongst other disciplines, geoscience provides a good context for studying recent developments in research-enhanced teaching as it epitomises one of the contemporary trends in academic research: highly multidisciplinary and interdisciplinary approaches for the coherent investigation of a given subject or issue. Scientific research on the Earth as an interconnected system draws on techniques and principles from a whole range of disciplines, from physics, chemistry, biology, mathematics to engineering and computing. It employs, often simultaneously, a wide range of research skills, including those that are field based, laboratory based and computation based. Effective education involving geoscience research has important influence on both undergraduate and postgraduate students. The next generation of geoscience researchers will have to be adept at using these skills and techniques in multidisciplinary and interdisciplinary studies for driving scientific innovations. Given the societal significance of climate change science, energy and water resources, a good understanding of geoscience research findings and methodologies is important for undergraduates who may not necessarily wish to become researchers.

The objective of this book is to highlight the importance of the research-teaching nexus at universities by using geoscience as an illustrative example. The focus is to showcase how geoscience academics have used innovative pedagogical approaches in teaching research skills and content explicitly and effectively. This book also aims to identify various perspectives on research-enhanced teaching in geoscience from different stakeholders, including students, industry partners as well as academics at different stages of their careers and in different capacities within their universities. The intended readership includes, naturally, the geoscience academics themselves. However, academics from other sciences and disciplines may also be interested in understanding how the research-teaching nexus can be effectively implemented. As technology plays a significant role in contemporary pedagogy, the chapters on how technology-enhanced learning has been integrated to facilitate the teaching of research materials and skills are directly relevant to the growing community of learning technologists. Academics responsible for the quality of teaching and learning at universities, those working in distance and adult learning, and in running faculty staff programmes for enhancing teaching quality would also find this book useful. The contributions in this book are also directly relevant to educators, particularly those interested in the relationship between education and academic research and in discipline-based education research. Together with the companion volume entitled *Geoscience Research and Outreach: Schools*

[2] *Discipline-based education research: Understanding and improving learning in undergraduate science and engineering*. The National Academies Press, 2012.

and Public Engagement (edited by Tong and published by Springer), this book demonstrates how geoscience research has played an important part in a wide range of educational contexts.

This book comprises two types of chapters: (1) perspective chapters highlighting current trends, challenges and solutions on issues related to the teaching of geoscience research and (2) full chapters showing innovative design and implementation of teaching projects enhanced by geoscience research. 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 five parts. In Part I, Marginson explains the historical evolution of the relationships between research and teaching in universities. As a leading academic in higher education policy, he explains how globalisation has shaped universities with different emphases on research and teaching around the world. Together with this chapter, it provides some relevant contexts for the four main parts of the book.

Part II of the book shows the diverse scope of the research-teaching nexus from the geoscientists' perspectives, and features three perspective chapters written by geoscientists taking different roles in university education. These three contributions are from geoscientists at very different stages of their careers, all sharing their personal views on the importance of research in university teaching based on their own experience. In Chapter 'The Challenge of Combining Research and Teaching: A Young Geoscientist's Perspective,' Cobden discusses her experience in teaching as a postdoctoral researcher and as a research student in three European countries. As an academic early in her career, she explains the difficulties in balancing research and teaching and proposes some solutions to the challenges she faces. The second chapter in this part outlines the benefits of using research articles and engaging students in research projects in undergraduate and postgraduate studies. As a current student who has studied on both sides of the Atlantic, McNutt details her experience and describes the reasons why she thinks research-enhanced teaching is important to geoscience students (Chapter 'Incorporating Research into Teaching Geosciences: The Masters Student's Perspective').

The third chapter is centred on the career-long experience of a professor from a research-intensive university in the USA (Chapter 'Teaching on the High Seas: How Field Research Enhances Teaching at All Levels'). Macdonald explains why field-based research and teaching have made him, in his own words, a 'better teacher and a better researcher'. He expresses the opinions that combining research and teaching is not always easy, and that the synergy between research and teaching needs to be cultivated but is worth the effort. Even though all three contributors advocate strong links between teaching and research, it is important to note that their chapters only represent the authors' own experience and may not be generalised. However, their viewpoints raised and discussed clearly highlight the different facets in the understanding of the research-teaching nexus and how personal experience may shape their approach to research-enhanced education. In the context of promoting research-enhanced teaching, perceptions of the educators and students could matter as much as the pedagogical innovations used in teaching projects.

Part III broadens the discussion, with five chapters showing how educators in different roles all working on promoting the research-teaching nexus in geoscience in their respective roles and contexts. Jenkins outlines his (and Healey's) widely cited framework in classifying research-enhanced teaching according to (1) the types of research materials and skills used in teaching and (2) the relative roles of teachers and students (Chapter 'Curricula and Departmental Strategies to Link Teaching and Geoscience Research'). From an education specialist's point of view, he explains how curricula and departmental leadership may help promote the integration of research and teaching in geoscience by citing and analysing a range of examples from different countries. Chapter 'The Role of Scholarly Publication in Geocognition and Discipline-Based Geoscience Education Research' highlights the contribution from scholarly journal publications to the promotion of research in geoscience teaching. As the former editor in chief of a geoscience education journal, Libarkin also discusses the academic study of geocognition, which takes a broader view of geoscience education research by investigating how the planet Earth is perceived and understood. This is an exciting interdisciplinary development in enhancing the teaching of geoscience concepts.

Promoting research-enhanced teaching may take many forms, and the third chapter in this part discusses the importance of the physical environment on teaching geoscience. Chan showcases the use of geological displays with multimedia contents at her university in the USA, and she identifies the key factors that contributed to the success of her project (Chapter 'Geologic Displays as Science and Art'). Chapter 'Teaching Geoscience Research to Adult Undergraduates and Distance Learners' shows that students who are more mature and those who study online should also benefit from teaching approaches led by geoscience research. Downes describes her experience of teaching this group of students at her university and explains the importance of final-year research projects, which may be used as the basis for students' contribution to peer-reviewed publications. The fifth chapter in this part describes the benefits of having closer links between industry and academia in research-based education. In Chapter 'Geoscience Internships in the Oil and Gas Industry: A Winning Proposition for Both Students and Employers', Ackermann and MacGregor describe the role of internship in the oil and gas industry. This is important because the energy industry is a significant investor in research and development and is one of the biggest providers of geoscience-related jobs for university graduates in many countries around the world.

Part IV of the book is a collection of chapters showing innovative uses of technology in a spectrum of research-enhanced teaching in geoscience. The first three chapters feature detailed analyses of student evaluation data, which are followed by two chapters showing trends in integrating technology in teaching geoscience research. Clary and Wandersee describe their project on using the students' local environment as the basis for an inquiry-based palaeontology course (Chapter 'Integration of Enquiry Fossil Research Approaches and Students' Local Environments within Online Geoscience Classrooms'). Together with Downes' chapter (Chapter 'Teaching Geoscience Research to Adult Undergraduates and Distance Learners'), their study provides insights into research-enhanced education for distance and adult learners. Their project is analysed both from a geoscientist's and an education specialist's perspective, and the pedagogical issues are discussed in the context of online learning and learning theories. The second contribution in this part (Chapter 'Embedding Research Practice Activities into Earth and Planetary Sciences Courses Through the Use of Remotely Operable Analytical Instrumentation') is special as the project brings instrumentation commonly used in research laboratories into undergraduate teaching. Ryan describes his project based on using remotely operable electron microprobe and scanning electron microscope in his class. According to his study, the hands-on experience on research instruments, thanks to the use of technology, has led to more interest in undertaking undergraduate research projects for his geology students.

The chapter by Stott et al. shows how the use of linked data and semantic web technologies has facilitated field-based teaching through the design and implementation of a virtual field guide (Chapter 'Using Interactive Virtual Field Guides and Linked Data in Geoscience Teaching and Learning'). The authors place their cross-faculty study in the context of teaching-and-learning research, and their experience underlines the increasing level of multidisciplinarity required in effective university teaching. Publishing research is crucial to a researcher's career, and Walkington explains how her project based on an electronic undergraduate research journal has helped her students understand the research process in geoscience (Chapter 'GEOverse – An Undergraduate Research Journal: Research Dissemination Within and Beyond the Curriculum'). The use of electronic platform facilitated the teaching as well as the publication process. The last chapter in Part IV continues with the theme by putting forward the case of forging closer links between research-enhanced and technology-enhanced approaches in university teaching. Tong discusses the novel uses of electronic feedback to and from students and explains their role in enhancing the quality of research-enhanced teaching (Chapter 'Towards Technology- and Research-Enhanced Education (TREE): Electronic Feedback as a Teaching Tool in Geoscience').

Part V of the book shows how programme design may impact on the teaching of geoscience research. The first three chapters in this part underscore the importance of the explicit use of geoscience research in teaching at different stages of undergraduate programmes. In Chapter 'Introducing University Students to Authentic, Hands-On Undergraduate Geoscience Research in Entry-Level Coursework', Guertin discusses the challenges of introducing research in introductory undergraduate modules, and the discussion is placed in the context of (1) rising participation of mature students and (2) students' wish to associate geoscience research with its wider societal impacts. She also shows the significance of citizen science programmes and interdisciplinary research in her chapter. The second chapter in this part describes t he design, implementation and evaluation of a module for first-year undergraduates at a leading research-intensive university (Chapter 'Engaging First-Year Students in Team-Oriented Research: The Terrascope Learning Community'). Bowring et al. discuss an inquiry-based project that involves using a wide range of pedagogical tools such as problem-based learning, field-based activities and the students' production of multimedia contents. Special attention has been paid to the development of students' communication skills. Chapter 'Students' Final Projects: An Opportunity to Link Research and Teaching' focuses on final-year projects, which are featured in many undergraduate programmes. Pereira and Neves discuss the considerations made in implementing a research-based programme for final-year undergraduates in geosciences. They highlight the importance of students' contributions to conference presentations and the use of virtual learning platform in the delivery of the project.

The fourth chapter in Part V describes a long-running pan-European inquiry-based project that underlines the increasing multidisciplinarity and interdisciplinarity in geoscience. Badía and his co-authors explain the implementation and evaluation of their field-based project, which was designed for a wide range of students from undergraduate to doctoral levels specialising in different subjects related to geoenvironmental science (Chapter 'Teaching Environmental Sciences in an International and Interdisciplinary Framework: From Arid to Alpine Ecosystems in NE Spain'). Last but not least, the chapter by Libarkin and her co-authors highlights the importance of effective assessment, curriculum and course development (Chapter 'The Role of Concept Inventories in Course Assessment'). More specifically, they demonstrate how assessments aligned to the intended learning outcomes can be achieved by the use of 'concept inventories'. The pedagogical points raised in their chapter are directly relevant to all research-enhanced teaching, and the approach adopted by the authors is by itself research oriented.

All the chapters in this volume are testimony to the vibrant support for the research-teaching nexus from geoscientists. Educators, researchers and academics working in different capacities and at different stages of their careers are all committed to enhancing university teaching through explicit uses of geoscience research. Their projects and perspectives make a compelling case for more innovations in the integration of research skills and contents in university teaching and in the human and physical infrastructures that support the integration. It is important to note that the examples in this book transcend the types of universities, teaching-led or research-intensive, and their support for research-enhanced teaching in geoscience extends to those operating in research and development in the industry. Whilst these examples lend strong support to the synergy between research and teaching, they also show the importance of the scholarly study of research-enhanced education in understanding and driving pedagogical innovations. As the quality of university teaching is being increasingly measured and made more transparent, research into research-enhanced teaching will make this pedagogical approach more robust and will thereby enhance its quality.

Teaching and Research in the Contemporary University

Simon Marginson

1 Antecedents

The first and most fundamental role of the university is and has always been that of teaching, for the various purposes of transmission of knowledge and values, person formation and occupational preparation and certification. At times the teaching mission has been joined to that of worship and religious ritual, at times to that of scientific inquiry and at times to serving the state and its institutions, but the production of persons through instruction and learning has always central to higher education. Whether done well or not so well, teaching has been the core social mission throughout the 1,000 year history of European universities and the 3,000 year history of university-like institutions in India, China, the Ancient Mediterranean and the Muslim world.

Famously, teaching was J. H. Newman's only concern in *The Idea of a University* (1852/1982). Newman's university was a teaching institution that covered all intellectual fields. It was not a research institution. It was concerned with 'the diffusion and extension of knowledge rather than its advancement' (p. xxviii). He did not expect academic staff to combine teaching and research. 'To discover and teach are distinct functions; they are also distinct gifts, and are not commonly found united in the same person'. Most of the major intellectual discoveries emerge from outside the universities, he said. But Newman's university was centrally concerned with knowledge, though it was received knowledge, and also with critical thought. Newman also saw as one of the chief benefits of the university the manner in which it brought the separate and competing intellectual schools together in the one place. The fields of knowledge were 'independent in themselves', he said, and each was supreme within its 'own department', requiring no higher or general authority; but

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they needed each other to be whole, being used to reflect on each other (pp. 35, 39, 52 and 58). The different fields 'complete, correct, balance each other' (p. 75). All contributed to the 'atmosphere of thought that every student breathed, even though the student might specialize in only one or two areas' (pp. 76–77). This made possible what he called 'liberal education', whose business was the formation of the intellect—though Newman was concerned only with male intellects. Women were not to be admitted to his university in Dublin for another 70 years.

Like the modern university as a whole, its contemporary research functions, and the notion of a teaching/research nexus at the heart of academic labour, date from the nineteenth century. In 1810 in Germany, Wilhelm von Humboldt (1970) made an argument for a new University of Berlin. He wanted to combine received wisdom with 'objective scientific and scholarly knowledge' including scientific inquiry designed to push forward the frontiers of knowledge (p. 243). His 'Idea of a University' was a teaching/research institution in which professors were free to teach and to inquire as they wished, students were mature, self-motivated persons, and received authority could be questioned. 'Science and scholarship do not consist of closed bodies of permanently settled truths', he stated (p. 244). 'One unique feature of higher education institutions is that they conceive of science and scholarship as dealing with ultimately inexhaustible tasks: this means they are engaged in an unceasing process of inquiry' (p. 243). Knowledge was often central to the university before this. The difference now was that it was provisional, open to continuous criticism, change and evolution.

There are questions about whether the implementation of these ideas in Germany was derived primarily from Humboldt. Ash (2006, p. 246) argues that some practices associated with the German research university arose prior to the University of Berlin and others later, and the generic 'Humboldt model' as such was largely the creation of government-driven university modernisation in Germany at the beginning of the twentieth century. In the twentieth century, the Humboldt model was mobilised to support the predominance of the professoriate in university affairs, the teaching/research nexus and the status of basic or pure research vis-à-vis applied research. Regardless of the origins of the model, it took time for German ideas about the role of research and critical inquiry to be diffused beyond Germany. In this, the United States was decisive.

Beginning with the Graduate School model developed at Johns Hopkins University, where nearly all the faculty had been German trained (Fallon 2007), in the last quarter of the nineteenth century and early twentieth century, the research mission was installed in American institutions. In the US context, especially in the land-grant institutions, research—in contrast with the Humboldt model, there was something of a bias to the applied side—was often associated with the service mission and with economic development and innovation (Scott 2006). These associations with research have now become common to innovation systems in many countries. After World War II in the United States, Vannevar Bush developed the famous argument about basic research in science as the 'seed corn' of useful discovery and technological advance. This resolved the tension between basic and applied research by advancing the notion of strategic basic research. Research was to be controlled autonomously by faculty, but there was an understanding that its ultimate rationale lay in innovations applied to human betterment and American national interest. The seed corn argument supported a great expansion of government-funded research, much of it sponsored by the federal defence department, or nuclear-related research funded by the energy department, or NASA research related to the space race, all driven by Cold War rivalry.

By the early 1960s, research occupied a pivotal role in Clark Kerr's (1963/2001) vision of the multiversity in *The Uses of the University*, which is still the best description of the contemporary institution. Kerr noted that a small number of American universities dominated federal research funding. In 1960, federal research funding provided 15 % of university income, with 57 % going to the leading six institutions (pp. 40–41). Nevertheless the research ethos had become more widely established in universities. 'Knowledge', stated Clark Kerr, 'has certainly never in history been so central to the conduct of an entire society' (p. 66). The American research university, he said, 'has demonstrated how adaptive it can be to new opportunities for creativity; how responsive to money; how eagerly it can play a new and useful role; how fast it can change while pretending that nothing has happened at all…' (pp. 34–35). At the same time, research-related reflexivity and the spirit of continuous criticism and development had become part of the culture even of university administration.

Since Kerr's time research has become ever more important, to the point where it now performs a whole range of separate social functions in higher education. Research is the source of new knowledge and industrial innovation, yes. Research underpins cutting edge teaching, especially at graduate level. Research also differentiates the research university from other social institutions (Considine 2006), and research performance stratifies the academic labour force between high and low achievers. Likewise it stratifies the different universities into high status and lower status categories. Stellar research achievement is essential to the high value of leading university 'brands' such as Oxford and Harvard, and research performance is the primary element that determines university rankings. Yet, research, which is a divisive force in these moments of stratification, is also a unifying force in other respects. Research inquiry and its more widely practised cousin, critical scholarship, are widely seen as missions and behaviours common to the academic profession. Here research, broadly defined, is not just a claim to social utility but a self-identity that professional academic faculty hold dear. Humboldt's teaching/research nexus continues to function as the ideological bedrock of academic labour.

2 The Global Research University

Kerr also predicted the transformation of world higher education along the lines of the model of the American research university (p. 65). This last prediction has turned out to be correct. In the most recent 60 years, university science and the research university model have become diffused throughout the world. It is not quite everywhere. For example, the research role of leading universities in Russia remains problematic: Russia has by no means completed the transition from the Soviet model of a zero-sum division between separate government research institutes and teaching-focused universities (Smolentseva 2007). But most other countries where research was separated from teaching, including China, France and Germany, have moved or are moving towards the comprehensive university model along the lines described by Clark Kerr.

Much of this diffusion of the role of the university in research science is recent, especially in East Asia. University research was initially dominated by the English-speaking countries, Western Europe, Russia and then also Japan. There are now 48 nations or systems in which more than 1,000 science papers are published each year in recognised global journals, compared to 38 such nations or systems in 1995—an increase of 26.4 % in 14 years (NSF 2012). Most such papers are from universities, though government research labs remain important sources of science in some countries. Diffusion of the research role is not complete. In the majority of sovereign countries, the output of research science remains small or negligible. But it continues to spread. The next zones of accelerated research performance may be Saudi Arabia and the Gulf States, which there have been marked recent investments in research capacity. Iran has already seen a major jump in research output in the last 10 years.

Table 1 lists all the nations that published more than 200 journal papers in geosciences in 2009. This is a shorthand way of assessing the global diffusion of research in the discipline. It underlines the fact that the research role is spreading but is not yet universal to all higher education systems.

Has the university as an institution been changed by this diffusion of the research role? Nearly all that Kerr described as essential to the 'multiversity' is still in place. But there are two additional elements. Arguably, together these elements have created a new version of the university. The first element is globalisation: not just the globalisation of knowledge (which was long part of the university) but the globalisation of vision and association. In Kerr's time, the practical horizon of higher education was the nation, while its imaginative horizon was the universe. Now the practical horizon is that of the world. This is closer to the imaginative horizon. The second new element is the knowledge economy—the growing role of knowledge intensive production and the strategic centrality of industrial innovation. The 'new knowledge' that excited Kerr has moved from being a large piece of the 'Idea of a University' to the dominant motif for the whole. We have shifted further from Newman's teaching-only university.

Globalisation is the process of partial convergence and integration across national borders. Today's globalisation is above all a product of the one world communicative environment that emerged in the early 1990s. The world is becoming one zone of association in which all human activities interface with each other and with a common store of knowledge (Peters et al. 2009; Marginson et al. 2010). The system of communications, information and knowledge constitutes a single world mind.

Table 1 World production of journal papers in geosciences, 1995 and 2009: Nations with more than 200 papers in 2009

National research system	1995	2009	Change from 1995 to 2009 (1995 = 1.00)
Anglosphere			
United States	9,852	11,620	1.18
United Kingdom	2,365	2,616	1.11
Canada	2,096	2,246	1.07
Australia	1,099	1,643	1.49
European Union (excluding UK)			
France	1,461	2,258	1.56
Germany	1,261	2,066	1.64
Italy	627	1,541	2.46
Spain	566	1,535	2.71
Netherlands	588	651	1.11
Portugal	78	524	6.72
Sweden	462	510	1.10
Poland	138	353	2.56
Belgium	181	351	1.94
Denmark	274	347	1.27
Greece	140	322	2.30
Finland	238	275	1.16
Czech Republic	91	258	2.84
Austria	146	239	1.64
Other Europe			
Russia	719	948	1.32
Switzerland	294	642	2.18
Norway	373	624	1.67
Turkey	104	576	5.54
Asia			
China	306	3,598	11.76
Japan	1,454	2,132	1.47
India	385	1,022	2.65
Taiwan	165	767	4.65
South Korea	64	663	10.36
Latin America			
Brazil	164	723	4.41
Argentina	99	357	3.61
Mexico	111	343	3.09
Middle East and Africa			
South Africa	255	312	1.22
Iran	9	308	35.33
Israel	183	228	1.26
World (all countries) including those with less than 200 papers	27,659	45,240	1.64

Source: National Science Foundation (NSF) (2012)

This is a staggering change, with consequences we cannot yet see, and higher education is at the centre of it. The world remains diverse in political, linguistic and cultural terms; nation states are robust and political economy continues to be partly national in form: the global knowledge economy is primarily integrated by 'knowledge', language and communications rather than 'economy'. But the different nations and cultures are transparent to each other, and creativity in all its forms, from scientific discoveries to management innovations to works of art, is now universal in reach. Successful human traditions are projected and reproduced not just on the national but the global scale. We begin to glimpse the future world society.

Globalisation combines the economic and cultural, and both are implicated in higher education. The roll-out of communications, knowledge and global English facilitates the evolution of world finance and trade. Trade, profit and growth propel the growth of transport and mobility, communications, knowledge and cultural universals. The economics of networks favours continuous expansion. As each node joins the network, the unit cost is the same. The unit benefits increase. Each node connects to a growing number of others. The cost function is linear and the benefits exponential, so networks expand at an increasing rate until universal coverage is reached. Hence the extraordinary dynamism of networks, and their quasi-democratic inclusiveness (Castells 2000, 2001). OECD surveys show that some countries in North America and Europe are approaching 80 % home computer access and broadband Internet per 100 persons is approaching the 50 % mark.

To higher education, globalisation has brought the accelerated mobility of researchers, university administrators and students; the cross-border market in degrees partly sustained by globally mobile graduate work; global e-learning, transnational education and foreign campuses in East and Southeast Asia; global networking and alliances, twinning and other partnerships; and global referencing, including global rankings with their transformative effects. The potential for cooperative global activity has grown, including combined research and teaching programmes. At the same time, there has been a partial global convergence across the world's universities, in their academic behaviours and institutional forms and in the Americanised political economy of the sector—parallel evolutions between national higher education systems, including the corporatisation of public institutions and their partial autonomy from government; mixed funding and partly private systems, external engagement and nominal student-centredness; more professional executive management and executive steering; quality assurance; and the doctoral training of professors according to increasingly common international norms. In sum, international relations have moved from the margins to the centre of the 'Idea of a University', especially in research.

There will be no return to purely national or local models of the university. Universities that turn their back on globalisation will wither. The national and local dimensions are still important. Non-research higher education is primarily national and local. Research-intensive universities continue to work these dimensions and are closely shaped by national policy and investment. But research universities are also closely shaped by global flows. They are 'glo-na-cal' institutions, global, national and local at the same time (Marginson and Rhoades 2002). J. H. Newman's 'Idea of a University' and Clark Kerr's 'multiversity' have become the Global Research University, or GRU.

3 Teaching and Research in the Era of the GRU

The Global Research University is now the leading model of higher education, and it is the form of institution that attracts the largest funding and the primary social status. However, in numerical terms, the GRU is not the dominant model. At the same time as the research role of universities has become diffused to many countries, educational participation has continued to advance. The global rate of participation of young people in tertiary education institutions exceeds one quarter of the population. In many nations, half or more of young people are enrolled in tertiary institutions; in South Korea and Taiwan, the ratio exceeds 85 % (UNESCO 2012). Most tertiary education institutions, however, are not research-intensive universities. They are not Global Research Universities. They are not Humboldtian universities in the sense of being founded on the unity of teaching and research. They are teaching-only institutions.

Even within the Humboldtian GRU, the research-intensive universities where most of the contributors to this volume are located, the teaching/research nexus is now under increasing pressure. There are a number of reasons for this. Teaching is universal, pastoral, egalitarian and inclusive in form. Research is selective, removed and also hierarchical. As research becomes ever more important, the differences between these two forms of activity become increasingly obvious. The two sets of functions are heterogeneous, the interfaces are complex, and the synergy must be constantly worked on. The synergy starts to fray when workloads in one or both domain become too high.

The synergy is not reciprocal. While an engagement with research lifts the insights that can be brought to teaching (a quantitative increase in research lifts teaching quality), teaching tends to detract from research because it cuts into the available time (teaching reduces research quantity and may weaken the intensity of engagement with research, impact negatively on research quality).

The nature of GRU itself has brought further pressures to bear on the teaching/research nexus. Governments, prospective students, employers and universities themselves place a growing store by university rankings (Hazelkorn 2011). Most rankings are entirely or largely driven by research performance (SJTUGSE 2012). To improve rankings, university managers often favour practices of internal resource concentration whereby the number of research-only positions is increased and strong researchers are provided with resources that enable them to reduce their teaching or give it up altogether. In some countries, including the United States and Australia, the proportion of academic positions that are designated 'teaching-only' appears to be growing. These tendencies to split teaching and research are exacerbated by other trends, including a growing reliance on casual labour ('part-time faculty' in the US nomenclature) for teaching and the growing divergence in university organisation, between teaching-focused undergraduate programmes and graduate schools with research activities attached. The growth of online education, including its new form, free teaching programmes provided by high status academics (MOOCs or Massive Open Online Courses)—with assessment and certification provided using automated Internet services—adds to the teaching-only forms now available and poses the possibility that some undergraduate teaching could be phased out or partly replaced by the MOOC form.

Despite these trends that threaten to undo the teaching/research nexus, at this time the core of academic labour in research universities like the contributors to this volume remains committed to the nexus. The teaching/research nexus still offers what it has always offered—the potential for research inquiry and its breakthroughs to support exciting contents and forms of learning, so drawing from raw students in formation the next generation of creators.

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Part II
Research-Teaching Nexus in Geoscience: Perspectives

The Challenge of Combining Research and Teaching: A Young Geoscientist's Perspective

Laura J. Cobden

1 Introduction

Working as a postdoc is the academic equivalent of being in limbo: Having completed graduate school, the young scientist passes from one short-term job contract to the next, often bouncing between institutions and countries, in the hope of eventually obtaining a permanent position as a lecturer or professor. Pressure to produce extensive, high-quality research is high, whilst teaching requirements are generally low and, in some cases, even zero. Yet, ironically, once a postdoc does obtain a permanent position, teaching obligations usually increase significantly, to the point where research output vanishes in the first 2 years. Teaching experience gained during the postdoc period is therefore highly valuable. Conflicts of interest between funding bodies, personal research interests, long-term career objectives and short-term survival can make it difficult for postdocs to include teaching in their schedule whilst maintaining a high research output. In this chapter, I draw on my own experience as a postdoc in several European countries to elaborate on the challenges and opportunities presented to young scientists who wish to combine teaching experience with effective research.

2 Teaching as a Young Scientist

2.1 Incentive to Teach

Perhaps surprisingly, during my 7 years of working in academia (4 years of Ph.D. and 3 years of postdoc employment), all the teaching I have undertaken so far has been entirely optional. If I had chosen, I could have spent the entire time

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performing only research. What motivation is there for young scientists, many of whom may not remain in academia for the long term, to teach? Like most UK geoscience Ph.D. students, my first teaching work was as an assistant, or demonstrator, in the practical classes accompanying a lecture course. These classes ranged in content from solving mathematical problems and studying rocks through the microscope to supervising fieldwork and geophysical modelling. The work was paid by the hour at what I considered to be a generous rate, and it provided a significant addition to my income on top of the regular Ph.D. stipend. Nonetheless I thoroughly enjoyed my teaching hours and I believed it was my love of teaching that motivated me to apply for and accept as many teaching hours as I could find. It provided a welcome break from sitting in front of the computer all day; it was dynamic and allowed me to talk to people, and I enjoyed the mental stimulation of having to respond to students' questions immediately in a clear and comprehensive manner. Thus, when I began my postdoc, I immediately made it clear to the more senior members of staff that I would like to be given some teaching duties, although this time I would not receive any extra money for such work. It came as a surprise to discover that under postdoc circumstances, my enthusiasm for teaching was not the same. Firstly, the financial incentive had gone, and, secondly, working on a 2-year contract, I did not have the leisure of excess time afforded to Ph.D. students. Instead of looking forward to teaching, I found myself feeling annoyed that it was eating into my research time. I still enjoyed the teaching hours, but I had to make a conscious effort not to allow the energy I put into my classes to be dampened by the enormous pressure I felt under to generate research results.

2.2 Opportunities

In the majority of cases, postdocs are funded by national or international governmental agencies for the purpose of carrying out a specific research task. There is neither provision for nor contractual obligation to undertake any teaching. Meanwhile lecturers and professors appreciate assistance from their postdocs in sharing their often large teaching loads. There is thus a conflict of interest between the funding agency and the research institution, as well as the professional development of the postdoc. Fortunately in my experience, most postdoc supervisors recognise the time constraints that a postdoc has and allow them to teach as much or as little as they choose. This is advantageous in the sense that the postdoc has the freedom to try different types of teaching – lecturing, running practical classes and supervising short-term BSc or MSc research projects – without it becoming a full-time activity. It can take several days to prepare a single lecture from scratch, so to teach a complete lecture course (typically one to two lectures per week for a duration of 2–3 months) is not advisable.

Whilst working as a postdoc in the Netherlands, I had the opportunity to design and supervise a computer-based practical exercise for 4th year students, running on one or two mornings per week for 6 weeks. The time required for designing the practical was only a few days, after which the only requirement was to be present during the 2 h of the practical class each week to answer students' questions, and I believe that at this level, the impact on my research output was negligible. The major advantage of designing the course myself was that I could tailor it precisely to my own expertise; when one assists on a practical class written by somebody else, one can prepare answers to the problems in advance but can rarely achieve the same depth of understanding of the material as the person who wrote it. Alongside the practicals, I also had the chance to deliver a couple of lectures from the lecture series associated with the practicals. Although I was given the original lecturer's slides to use as a template, it took far longer to prepare for the lectures than the practicals. This was mainly because I had to read around the subject in textbooks and refresh my memory of topics I had forgotten, to be confident that I could deliver the material coherently. I also had to prepare to be able to talk in detail, without interruption, for up to 90 min about the lecture material, in contrast to the practicals, where most talking was in response to students' occasional questions. Nevertheless, the experience gave me a good insight into the working lifestyle of someone with a permanent academic post.

2.3 Training

Formal teacher training opportunities and requirements vary between institutions. In my own case, the only official "training" I ever received was a 1-h presentation during the first year of my Ph.D. on how to demonstrate in practical classes. This provided some useful tips, such as to be careful not to spend disproportionately longer times with some students than others (i.e. do not show favouritism) and not to go into too much scientific detail when explaining a concept on an introductory-level course – in particular, we should avoid talking about our own research projects. Beyond that, I learned to improve my teaching technique simply by experience – by listening to feedback from the students and trying to remember what teaching styles I had appreciated from my own lecturers and demonstrators when I was an undergraduate. For example, the students told me that they did not like it if I spent too much time talking to them when trying to explain a concept – they preferred it if I asked questions which directed them towards the answer through their own reasoning. I also learned that I had a tendency to talk too fast, especially when I began teaching in the Netherlands and Germany, where English was not the first language of the students, and I had to remind myself continually to talk slower than usual. Thus, although minimal formal training may be provided for postdocs, teaching well in a university environment depends more crucially on the interest and motivation of the postdoc to develop their teaching expertise from observations of students and other lecturers.

3 The Link Between Teaching and Research

3.1 Benefits for Students

Does a good researcher equal a good teacher? At one point during my Ph.D., I considered pursuing a career purely in teaching and without any scientific research. Apart from the fact that teaching-only positions at universities are few and far between, I have come to recognise that teaching and research are complementary, and being actively engaged in scientific research can enhance ones' teaching capabilities. Especially in the field of geosciences, which is relatively young and rapidly evolving (we can consider that modern-day geology began in the 1960s following the discovery of plate tectonics), we find that the topics taught in undergraduate courses will often change on a time scale of just a few years. Performing your own research ensures you are "on top" of the latest developments, through regular interaction with other geoscientists at meetings and conferences and by reading the newest journal publications, and therefore keeps your teaching material up to date. Non-researchers can of course still read scientific papers, but in my experience, I only think about the work presented in great depth when there is a specific problem to solve or question to answer related to my own research. Furthermore, non-researchers would be unlikely to have the funding to attend international conferences, whereas a researcher usually has a budget which allows for long-distance travel when required.

Continuing to perform research in parallel with teaching not only ensures that the teacher has a good general overview of the status quo in geosciences but allows them to incorporate aspects of their own research into their teaching. For example, the computing practical which I designed in the Netherlands was developed from a section of my Ph.D. work. In the practical, the students were asked to create different models of the Earth's deep mantle and compare them against real seismic observations, to see if they could place constraints on the temperature and chemical composition of the deep Earth. The practical had multiple benefits: it gave the students an insight into the process of performing scientific research; it provided a more proactive form of learning than passively sitting in a lecture hall; it made the course more varied than lectures-only; and it allowed them to see how the thermodynamic theory and equations presented during the lectures, which might otherwise seem dry and irrelevant, may be applied to solve a real problem about the Earth.

3.2 Case Study: A Research-Based Practical for Students

In the first part of the practical, the students performed simple "forward modelling" tests, in which they used a numerical modelling code to calculate seismic wave speeds inside the mantle for different temperatures and chemical compositions. The idea behind this was that by calculating the wave speeds themselves via manipulation of a code, and displaying the results graphically, they would understand and remember better what effect temperature and chemistry changes have on seismic wave speeds, than if I had just told them verbally in a lecture. The code itself was greatly modified from the original version which I used during my Ph.D., so that the students could use it as a "black box" and simply input a small number of parameters, type "run", and the seismic velocities would be output several minutes later. This simplification was due to time and scope constraints – for this particular course, I wanted the students to focus on understanding the Earth, rather than spend many hours advancing their programming skills.

The second part of the practical was intended to test whether the students had fully understood the first part and required a significantly higher level of thinking. In this part, rather than asking the students to calculate the output for a given set of parameters, I provided them with a set of seismic data for the Earth and asked them to deduce what temperature and chemistry would fit the data. The problem was complex because there was more than one solution to the problem, and both the mineralogical data (from lab experiments) which fed into the numerical modelling code and the seismic data are associated with large uncertainties. Thus, I hoped to introduce the students to the concept that there isn't always a "right answer", and that we need to be aware of the uncertainties on the data and the limitations that these place on our interpretation of the results.

We sent an anonymous survey around the students on completing the course for feedback on how useful they found it: two-thirds of respondents felt that the practical improved their understanding of the material presented in lectures, and 83 % agreed that they learned something about the structure and composition of the deep Earth as a direct result of completing the practical. 100 % of the students responded positively or neutrally to the statement, "Overall, I enjoyed the practical". This exercise demonstrated to me that undergraduate students' learning experience can be significantly improved by allowing the students to undertake their own mini research exercise and incorporating aspects of one's personal research into the course.

However it was perhaps less satisfying to discover that only 50 % of the students felt that the practical gave them an insight into performing scientific research. Some of the students said that it would have been more realistic if they had been given more computer programming tasks to do. This would have been difficult within the time allocated to the class and the mixed background of the students (some geologists and some physicists). One aspect of the practical which the students complained about the most was the fact that they had to run the numerical modelling code many times as they changed different input parameters. Each model took up to 15 min to run, and some students felt that it was boring and a waste of their time to keep running the same code over and over again. However, I felt strongly that it was important for them to learn that this is how scientific research is: not every day is exciting, and often the tasks required are menial and repetitive.

By accident, I also discovered that the students benefitted more from working in pairs than individually. The first year that I ran the class, we had limited computers, so the students had to work two to a machine and submit a joint report at the end of the course. In the second year, we had more computers and the students worked individually. I had assumed that working alone would encourage the students to think more individually and produce a more detailed report. In fact, the opposite happened and they used their brains less, because when the students were working in pairs, it stimulated a lively discussion between them about how to answer the practical questions. This also meant that the students asked me many more probing questions about the Earth and the thermodynamic theory to resolve their discussions.

As a result, the submitted reports from students working in pairs were based more on thinking about the physical meaning of their investigation than mechanically answering the questions. For example, in the second part of the practical, the students were supposed to use their understanding of the relationship between temperature, chemistry and seismic wave speed to predict what thermochemical structures might fit seismic observations. A number of students working alone did not see the connection and were simply picking models with randomly chosen temperature and composition, until they arrived by chance at a solution which fit the data. I also suggested to the students that they might use published literature to get some ideas about what sort of temperatures and chemical compositions are appropriate for the Earth. In the year where the students worked in pairs, they did not have time to perform a literature search before the practical deadline, due to time spent discussing the problem. The students working alone did have the time, but they simply used the published thermochemical models in the literature as direct input to the code and, when the output did not fit the data, stated that they had tested model X from paper Y and it did not work, rather than using it to guide them towards a solution. To my amusement, none of the students had the idea to read my own publications, which would have aided them significantly in answering the practical questions. The main lesson I learned from these observations is that when presented with a research-based problem, undergraduate students do not make the same connections between different ideas and datasets that an experienced researcher might. Where needed, I should therefore explicitly guide them in the right direction, and verbal discussion with and amongst the students can help to promote the required leaps in logic.

3.3 Benefits for the Scientist

Despite the lack of financial incentive and the large time restrictions, teaching experience gained as a postdoc is not without advantages. First and foremost, anyone aiming towards permanent post at a university cannot escape from teaching forever. Virtually all permanent positions within a university environment (as opposed to an independent research institute, which may or may not exist for a postdoc's particular research expertise) require a certain number of teaching hours per academic year. Therefore, accepting minor teaching responsibilities whilst working as a postdoc can help a person to decide if this is really the career path they wish to follow. It also provides them with important teacher training which they would not otherwise formally receive. For these reasons, potential employers like to see that a job candidate already has teaching experience as well as an interest in teaching, and any existing experience can gain them valuable "CV points".

Another advantage of undertaking teaching is that it can actively feed back into ones' own development as a researcher. For example, giving a lecture to a large audience of students provides good practice at presenting scientific material clearly and engagingly, which may help the researcher to present their work compellingly at conferences. From my own experience, I have learned to speak more slowly and not to present ideas that are overly complicated. When assisting another lecturer with their course, the postdoc is often forced to teach subjects outside their own particular specialism, and this broadens their own scientific knowledge which may lead to new ideas for tackling research. Finally, training students to conduct their own research project is both rewarding in its own right and may produce results which the postdoc can use directly for publication.

Overview

Status Quo and/or Trends

- The postdoctoral scientist may have access to a wide variety of teaching opportunities but has limited time in which to undertake such duties.
- Teaching duties are largely optional, whilst research demands and workload are high.
- Teaching may consist of assisting in practical classes ("demonstrating"), delivering lectures, designing new lectures or practical classes and supervising students with minor research projects.
- There is little formal teacher training.
- A career which combines teaching with research enhances the quality of both.

Challenges to Overcome

- It is difficult for postdocs to find time to complete both research and teaching tasks effectively, leading to overworking and high stress levels.
- There is no financial reward for teaching.
- There is no incentive to teach for scientists wishing to pursue non-academic and/or research-only career paths.

Recommendations for Good Practices

- Postdocs teach sections of a particular course or module, rather than undertaking a complete lecture course.
- Postdocs self-train how to teach using feedback from students and observations of other lecturers and their lecture material.

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- Postdocs actively consider the connection between teaching material and the latest research, perhaps finding a way to incorporate their research work into classes.
- Senior members of staff (permanent lecturers and professors) remain aware of the time constraints and research pressures which postdocs face and therefore do not demand excessive teaching hours from their postdocs.
- Senior members of staff may provide materials (e.g. lecture notes, slides) from previously taught courses to help postdocs assemble their own lectures.

Incorporating Research into Teaching Geosciences: The Masters Student Perspective

Barbara McNutt

1 Introduction

When I was asked to share my personal reflections on the relationship between research and education in the geosciences, I was excited to discover that I had so much to say about the subject. Even though I have never studied any theories of learning or done an education degree, I can speak with certainty about the positive learning outcomes I experienced as a student who has been exposed to research in my university courses.

In 2005, I began a part-time Bachelors of Science in Geology at Birkbeck, University of London. In 2010, I returned to the United States and began my Master of Science in Applied Geosciences at the University of Pennsylvania. It was not until embarking on a new career path in geosciences that I started to think about the role that conducting research and reading others' research played in education.

As a B.Sc. student, I was a little mystified by how lecturers conducted their research, and I was grateful for every insight into the process whereby the geosciences student becomes the geoscientist. When choosing my Masters program, I remember liking the sound of *Applied* Geosciences – I would apply my knowledge in real research exercises and become part of the academic research community to whom my lecturers belonged, the community whose journal articles I read! I would be "learning the ropes" and taking part in research internships and career training. As far as I was concerned, the more that research became interwoven with learning, the better. At Masters level especially, I expected to engage with the research side of higher education. I wanted the role of the lecturer as a teacher to merge with the role of the lecturer as a researcher. I wanted my geosciences degree to teach me how to

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be a scientist and equip me with the professional network and the skills to succeed at working in a geoscience field through conducting research.

This chapter explores the geoscience student's experience of research being incorporated into university level learning in those ways. I cite a particular case study from my own experience, the Advanced Earth Surface Processes course taught by Professor Douglas Jerolmack, as an example of research being incorporated very well into geosciences teaching. The learning outcomes achieved through the research and fieldwork incorporated into this course are outlined and discussed. I generalize from this and other cases how the use of research to explain geoscience concepts and skills has proven effective.

2 Experience of Research Articles Incorporated into Learning

In my experience as an undergraduate and postgraduate geosciences student, research articles have frequently been incorporated into course assessments and teaching. Often lecturers would provide key articles to students to ensure we understood a certain concept and its applications. In the field of geophysics, for example, my lecturer would incorporate articles into assignments to test comprehension of particular seismic methods; these articles would be chosen to reinforce the connection between the physics and math concepts in course lessons and how they can be usefully applied to model and make predictions about subsurface features like subduction zones. These articles taught me by example and repetition how to present and structure the discussion of geoscience data and gave me a familiarity with how to present an idea through data.

3 Experiences of Field Research Incorporated into Learning

It has been reported that inquiry-based field research actively engages geoscience students and can increase learning and comprehension (NRC 2000; Minner et al. 2010). I can report very positive learning outcomes from instances where my lecturers have incorporated both their own research and research-gathering exercises into their course. In fact, in the case of an Advanced Earth Surface Processes course I took in 2011 at the University of Pennsylvania, I experienced the best possible outcome from a student's perspective, coauthorship of an article that was accepted at a research conference based on fieldwork research conducted through the course.

This course, taught by Professor Douglas Jerolmack, was offered to Masters students and advanced undergraduates and included a voluntary weeklong research-gathering field class to the gypsum dune fields at White Sands, New Mexico. On the first day of class, our lecturer announced the dates for the field trip and said that it would teach us how to conduct research and help us learn the concepts of the course (Jerolmack, personal communication, January 2011).

In the course, students began by reading several research articles which explained the construction of equations used to describe sediment transport in rivers and aeolian sand dune formation, among other key principles. To ensure a greater understanding of the published research and to enhance our familiarity with the field site, students were paired to do presentations on aspects of White Sands. My presentation partner and I discussed the different dune types there, how they differed, and how they formed.

Our field site was described as a place where published research was continuously produced, and our preparation for the trip involved reading such research published about White Sands. We read articles in *Geophysical Research Letters* that our lecturer coauthored based on his White Sands research, for example, "Barchan-parabolic dune pattern transition from vegetation stability threshold" (Reitz et al. 2010). Professor Jerolmack enthused to us that work conducted in our research teams could well form the basis of new research articles to be submitted for publication (Jerolmack, personal communication, March 2011) Some other researchers instructing us on the field class had also published articles about White Sands, for example, Professor Ryan Ewing and Ph.D. student Mr. Raleigh Martin.

4 Positive Learning Outcomes of the Course

Positive learning outcomes I can report from having taken the Advanced Earth Surface Processes course are as follows:

4.1 How to Interact with Different Members of a Research Community

The White Sands field class brought me into contact with people at all levels of research experience: academic researchers who wrote proposals for NASA at the California Institute of Technology, published lecturers, Ph.D. students working as teaching assistants, Masters students like myself, undergraduate students, and national park rangers. It was an enriching experience to see how everyone's roles fit together to accomplish something great. I enjoyed the chance to watch professionals develop plans to test their hypotheses in the field and how they interact to get work completed.

A fellow student on the course, Ms. Mengdan Jiang, made a very good point that our professor and his research colleagues informed us of our role in the research, made us very aware how our activities contributed to the success of the effort, and what that effort might lead to in the future (M. Jiang, personal communication, May 11, 2012). Students felt like active participants and insiders in a research community, motivating us to produce quality data for ourselves, for our teams, and the White Sands project as a whole. This was the ideal environment in which to learn how members of a research community interact productively. Hasok Chang (2005) spoke of creating a research community on his University College London course; in his "directed-community model," Chang had his class interact with professors and previous students whose research served as secondary literature. Chang asserted that this method, "breaks down the imagined sharp barrier between themselves as mere students and 'real' scholars as famous people," (2005) and the application of this method on my course made me feel I could contribute valuable, original work and share it with others.

I also recognized in action on my course something like Chang's inheritance mechanism, an active connection to the research undertaken by previous classes in White Sands with which to compare or contrast my current research.

4.2 How to Organize and Mobilize as a Team to Produce an Experiment

My lecturer explained that each of his Ph.D. students was working to collect particular kinds of data, and we would form a team of researchers under each Ph.D. student. Students would spend 2 days in each team and then choose the particular data-collection team that interested them most. The teams involved vegetation analysis and soil moisture measurement for all portions of the dune field, GPR traverses along dunes and interdunes from barchans to parabolic dunes, teams to measure channel geometry and undertake grain size analysis, and teams conducting wind speed and sand entrainment experiments (Fig. 1). Professor Jerolmack explained theories about the evolution of the dune field and how there were still many unresolved questions to test (Jerolmack, personal communication, March 2011).

Once we were introduced to the teams and informed of their objectives, we learned how to plan, initiate, and conduct experiments and to allocate ourselves particular duties. Each person learned how to synchronize their efforts with one another to accomplish a research goal within a given time window.

I liked that we were empowered to choose the team that was the best fit for our interests. I was excited by the opportunity to use GPR and I was excited by the prospect of imaging the water table and cross-referencing it with another team's data for our site regarding groundwater depth in dunes and interdunes through augering, trench-digging, and soil moisture testing and salinity analysis. This freedom to choose my research problem and being included and informed in the questions being explored by all teams motivated me to learn.

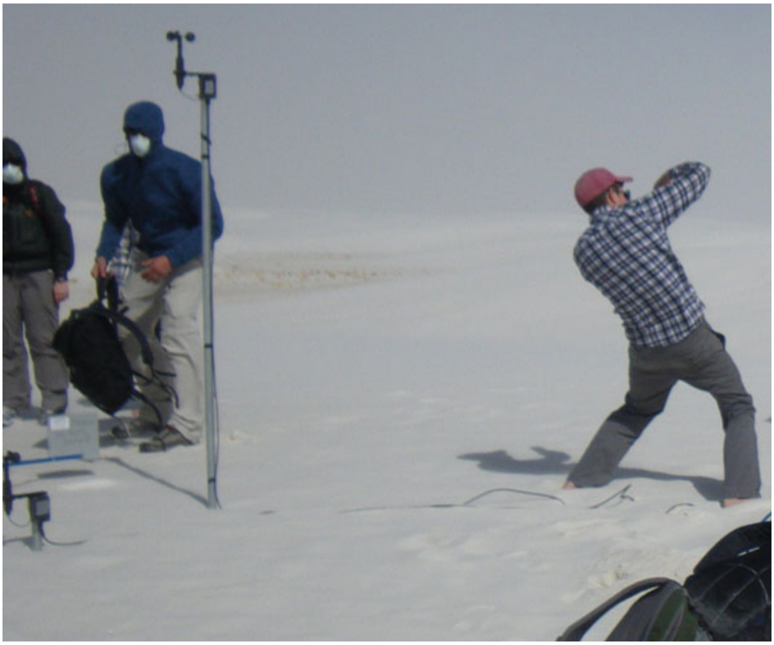

Fig. 1 Prof. Jerolmack and students setting up an anemometer experiment (Photo of White Sands, New Mexico Earth Surface Processes field class, 2012)

4.3 Learning the Steps Involved in Organizing a Research Plan

My lecturer explained the steps he had to follow in order to gain access to White Sands National Park to conduct our investigations. He shared with students the proposal he and his colleagues wrote in order to obtain the permit to conduct research in the park. He helped students understand the paperwork and the planning involved should we organize our own research excursions in the future (Jerolmack, personal communication Feb 2011).

4.4 How to Use Field Equipment and Data Correction Software, e.g., Ground-Penetrating Radar (GPR), **RadExplorer** *Software, Soil Probes, and Anemometers*

Each team had an experienced member to oversee the use of the equipment, to demonstrate how the equipment worked, how it should be set up, and who helped address any issues we might experience with the machines. Their demonstrations in

Fig. 2 The GPR team learning from Professor Ilya Buynevich (Photo of White Sands, New Mexico Earth Surface Processes field class, 2011)

the field ensured we learned how to operate the equipment. My team enjoyed an additional learning component; we got to reconvene in another professor's lab after the field trip for a *RadExplorer* tutorial and training session (Fig. 2).

4.5 How to Design and Construct Experiments Based on the Principles of Sand Entrainment and Sand-Transport Velocity Profiles

Ph.D. student Mr. Raleigh Martin explained to us that "White Sands is unique in that the geology is actually happening all around us…" and "when the winds are blowing, students get to measure the spatial variation in wind speed and sediment flux, confirming the theories they've learned in class" (R. Martin, personal communication, May 12, 2012). In White Sands I learned how to apply the equations used for describing sand transport to design and construct experiments. The equations I had seen in articles and in class stated that wind velocity varied with distance from the ground and explained the variables that governed the settling velocity of sand. It was fascinating to consider this when erecting sand collection devices with anemometers. Seeing firsthand how the power of those equations

Fig. 3 Constructing the traps for sand collection (Photo of White Sands, New Mexico Earth Surface Processes field class, 2011)

could be demonstrated in the dune field gave me a better grasp of the subject matter. I support the constructivist view of Abdal-Haqq (1998) that this type of inquiry-based learning activity deepens understanding and retention of knowledge. Most importantly, it revealed to me that equations don't just exist; they evolve from experimental observations of researchers (Fig. 3).

4.6 How the Research-Teaching Nexus Can Exist as a Model for Courses I Might Create or Teach

This course provided a great synthesis of the teaching and researching roles for the benefit of staff and students alike. A win-win situation for instructors and students, "instructors are especially motivated by the chance to pursue original research (with lots of helping hands), while students get exposed to the real research process" (Raleigh Martin, personal communication, May 12, 2012). I definitely think that, were I to teach at a university, this would be a great model to adopt.

4.7 How to Construct an Outline for a Research Article

Soon after we came back from our field work, and had applied our findings to address specific hypotheses about the dune fields at White Sands, we were given verbal and e-mailed instructions for constructing an outline for our research article that included a successful outline from our professor's Ph.D. student as a template. I appreciated having this template to follow into this new exciting terrain of research and a bullet-point list of pieces I needed to include. The same procedure was followed for the literature review and abstract, and this really helped me structure my research.

4.8 How to Submit Pieces of Research According to a Deadline Schedule

I liked that our research papers were broken down into manageable parts within a schedule of separate deadlines. Although it may seem to the experienced researcher like common sense procedure, it can seem like a new approach to a student. We had about 3 weeks to write our outline and literature review. The following week from that deadline, our 200-word abstract was due. Our professor e-mailed us feedback on our abstracts within the week.

Two weeks before the final paper deadline, students were allowed to submit a draft version. Professor Jerolmack advised us that those who submit a draft do consistently better on their papers, since substantial feedback would be given (Jerolmack, personal communication, April 2011). I submitted a draft and got lots of feedback with which to improve my paper. In submitting my research to my lecturer in successive stages, I was learning how professional article submission is done; it was good practice for submitting to journals and conferences.

4.9 Building Confidence as a Geoscientist

As a result of this course, in which research was well incorporated into learning, I felt more confident in my identity as a budding geoscientist. I was happy that this course was a great addition to my CV, showing that I could really go out on my own and conduct research in the future.

My positive experience with conducting research as part of a course of learning is not an unusual one; conducting research as part of a course of study is known to provide mentor opportunities, job training, and enhanced learning and performance in presenting and teamwork (Erickson 2001). I found similar positive experiences on the Voices of the Undergraduate Geosciences Research website, maintained by the Geosciences Division of the Council on Undergraduate Research. Podcasts of student research experiences at different universities are featured on this website, in which students often commented on their increased public speaking skills, teamwork skills, and professional career building as a result of conducting research (Guertin 2011).

Justice et al. (2007) stated that a McMaster University course incorporated inquiry-based structure and process, with the aim to "improve students' collaborative learning" and to equip students with the tools they will need for "navigating diverse, complex, and changeable careers." The inquiry-based learning employed in conducting research imparts crucial problem-solving skills transferrable to a variety of careers.

5 Experiences of Geosciences Courses with No Research Incorporated

My personal experience as a geosciences student has been that research incorporation into teaching, either through interpreting research articles or field-based research projects, is standard and effective practice. However, I did ask other geoscience students about their experiences. Where research was not included in their courses, I asked students why this might be the case. Our general conclusions were that the geology undergraduate courses we had taken that did not include a research component were introductory level courses which involved a lot of information transfer: memorizing rock types, rock things like Dunham's classification system for limestone, and concepts like the rock cycle and geological time. The aims of these courses were more to review concepts learned in earlier schooling, to test recall of basic information, and were not aimed at teaching any scientific skills because it was too early in the degree to expect that level and type of learning (Raleigh Martin, personal communication, 2012).

It may be that the most introductory courses need to be about familiarizing students with the terminology and different branches of geosciences, and that incorporating research into those introductory courses may be too much too soon. Spronken-Smith et al. (2009) spoke of this, "perceived need to become familiar with a base of knowledge and to learn the associated language and concepts of the discipline," before the challenge of conducting research can be undertaken by students. Once the basics have been taught, I believe that the sooner students become accustomed to thinking like a researcher in geosciences, the better, and I think that belief also underpinned the approach of the majority of my geoscience lecturers.

6 The Research-Teaching Nexus: Challenges

The research-focused field class in White Sands, New Mexico, is clearly a labor of love for my Advanced Earth Surface Processes lecturer. Each year he has to apply to a permit to access the national park, makes a case to our department to help subsidize the trip, and motivates and encourages a significant number of students to attend, enticing them with how much they will learn, the opportunities to get involved in crucial research, and how their attendance will excuse them from a difficult homework assignment. Each year he organizes an updated research article reading list and coordinates with other researchers and writers who will help him instruct the class.

Through all this effort, the White Sands field trip achieves a terrific symbiosis wherein the lecturer's shared objectives of teaching and research are very successfully combined with the student's joint motivation to learn and to conduct research. In this case, the academic's challenge of how to make time for one's research while teaching is overcome through combining both practices for the mutual benefit of staff and students. I think this field trip is an example of what geography lecturer and educational developer/researcher Alan Jenkins, an advocate for the research-teaching nexus, might view as one of those, "productive relationships between staff research and teaching, if teaching and research are conceptualized in ways that enable them to be effectively linked, and if staff research is 'managed' to benefit student learning" (Jenkins 2000). Being actively engaged in a research community, my lecturer has been able to coordinate a group of researchers in the same place and time for several years, and every year several research articles are published as a result of the new data gathered.

I think that this course strikes a successful balance, across the research-teaching nexus. As both someone who has both worked in universities and studied at them, the White Sands model strikes me as a good one to adopt because it really enables the lecturers and the students to make the most of their talents and time doing the very thing that funds their departments and institutions: the research. The course manages to creatively overcome the compatibility challenge between teaching and research, moving beyond the notion that one must thrive at the expense of the other.

In their meta-analysis of the relationship between teaching and research, Hattie and Marsh (1996) stated:

> The goal should not be publish or perish, or teach or impeach, but we beseech you to both publish and teach effectively. The aim is to increase the circumstances in which teaching and research have occasion to meet, and to provide rewards not only for better teaching or for better research but for demonstrations of the integration of teaching and research.

This course proved to me that this goal is achievable.

7 Recommendations for Good Practice

At Masters level, I think it is imperative that students conduct research firsthand, and that they are expected to do some original research as their final thesis or project. Good practice would be to give students plenty of opportunities and experience in doing this through the following:

7.1 Courses That Offer Optional, Incentivized, Research-Focused Fieldwork

If research-focused fieldwork is to be incorporated into teaching geosciences courses, it is a good idea to make it optional rather than mandatory. There is a time and money commitment associated with going to a field site that won't be possible for every student, so those disadvantaged students may need alternative projects. However, to maximize the number of students on the course who get to benefit from the fieldwork research experience, it is good practice to give plenty of notice about the possibility of fieldwork and specific dates when it will occur, so that students can prepare in terms of their family and financial commitments.

Another good way to maximize fieldwork research participation is through incentives such as exemptions from other coursework, by highlighting the chance to meet key researchers and to learn from them onsite, and by emphasizing how the experience will help build the student's career and skill set. By presenting research as an investment and an opportunity, voluntary participation can be popular and successful.

8 Recommendations for Integrating Research Articles into Teaching

I think that students choose a college or university based on its teaching profile and research profile, and many students understand that lecturers are hired based on the quality and quantity of their research. Reading some of my lecturer's research articles is something I typically do when I begin a course, and when that practice is incorporated into the course structure, so much the better.

In every geoscience course I have taken, I have observed in myself and others a real increase in interest when a lecturer goes over the specifics of their own research, how he/she designed an experiment, processed the data, and interpreted the findings. Research articles show us the best practice of how science is done and how to discuss our results; they are an important way of helping students relate to scientific concepts.

Research articles are also an excellent way to introduce students to essential skills like constructing curves and creating diagrams to illustrate and explain results. Practically every geoscience research article includes diagrams, yet for students like me, college- or university-level study may be their first exposure to data being plotted on a curve, and students like me may have never before been asked to construct such a diagram. When my lecturers have introduced students to one of their research articles and demonstrated in class how they compiled their data and plotted it on a graph to test their hypothesis, I have found it incredibly enlightening and helpful; it demystified the process of constructing diagrams, tying together the mathematical background I had with the best practice for how to apply it to data.

9 Conclusions

Ultimately, I think that research activities should continue to be incorporated into geoscience teaching as much as possible and that research-focused fieldwork is the best way to do this. It provides benefits to both teachers and students to have the researchers' role reflected in lessons. From a student's point of view, budgeting for this in courses is a practice with a terrific payoff in terms of student satisfaction, student employability, and accomplishing learning outcomes.

My point of view on the research-teaching nexus at universities is summed up by the question I have asked myself since studying geosciences: "Would my lecturers know how to write their research if they did their degree at the university where they teach, or would they have had to learn how to do that somewhere else?" Teaching which incorporates research means value for money to a student; Healey (2005) noted, for example, that Southampton University cited its research-led teaching and learning philosophy as a selling point to students and the wider academic community.

Students appreciate seeing what their lecturer does best; getting to see them in their element at research and getting to contribute to their research is what they are paying to experience. Therefore, the exciting challenge for universities is letting students experience the research-teaching nexus at its finest and showcasing the valuable teaching and research their lecturers have to offer students in new ways.

Overview

Status Quo and/or Trends

– The status quo for geosciences courses to include research in order to prepare students for a geoscience career
– Student experiences of geosciences teaching with and without research components
– Masters student perspectives on why lecturers do incorporate or do not incorporate research aspects into teaching
– Discussion of learning outcomes gained through research using case study of Advanced Earth Surface Processes course at the University of Pennsylvania: techniques of scientific inquiry, gaining a better grasp and knowledge of subject matter, and learning to adopt the role of researcher as potential career path

Challenges to Overcome

– Challenges within the research-teaching nexus? How can students, lecturers, and departments benefit from incorporating research into teaching?

Recommendations for Good Practices

– Converting the positive outcomes into recommendations for good practice.

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– Possibility of publication/conference presenting as motivation for students to conduct research on field trips.
– Masters students enjoyed conducting research as part of their Masters course curriculum, and students want to see their lecturers in their element conducting research as part of their learning curriculum.

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Teaching on the High Seas: How Field Research Enhances Teaching at All Levels

Ken C. Macdonald

1 Introduction

Teaching, especially undergraduate teaching, presents challenges at research-intensive universities where so much effort necessarily is devoted to raising funds through research grants (in a very competitive environment), organizing and executing complex international expeditions, building and maintaining high-tech laboratories, and publishing in high-profile research journals. However, there are opportunities for an invigorating symbiotic relationship between teaching efforts and research fieldwork. Both efforts are enhanced by bringing the field to the classroom and the classroom to the field. In my case, that field area and primary classroom are the world's oceans.

2 Bringing the Ocean to the Classroom

I never imagined myself standing in front of over 600 students and teaching them about exploring the world's oceans. It was all the more daunting because "Introduction to Oceanography" was offered specifically for nonscience majors who had to satisfy a general education requirement in physical science. For the most part, these students had done their best to avoid science in high school. What little exposure they received had left them feeling hopelessly stupid in science, or worse, numbingly bored by it. Even worse yet, I had never taught a class before; I had only given a few guest lectures to classes of 20 or fewer graduate students. "Introduction to Oceanography" was a very popular course at UC Santa Barbara, which is located

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on a peninsula jutting out into the Pacific Ocean. While not every student was a surfer, they all seemed to have an affinity for the ocean, occasionally looking up to see foam spewing off breaking waves as they rolled over on their beach towels to achieve that even tan. Perhaps they were ready to depart the beach at 2 p.m. to attend my class, often on such short notice that many were still distractingly clad in surfer shorts, bikinis, and sarongs. As the aroma of coconut oil quaffed toward me on the stage, I felt woefully unprepared to win over their attention and convince them that the latitudinal variation in Coriolis forces was something they should care about.

Up to that time, I had been a full-time researcher. I began my career as a graduate student in the MIT/Woods Hole Oceanographic Institution Joint Program in Oceanography, where course requirements were nil (at that time), teaching assistantships were unavailable, and students forged their own path as an apprentice to one or more senior researchers. The day after I defended my dissertation at Woods Hole, I began a 3,000-mile drive west to Scripps Institution of Oceanography in La Jolla, where raising grant funds, managing expeditions, and writing research articles constituted 100 % of a 60+ h per week vocation. I was a research monk; well, almost. Three years later, becoming a tenured associate professor was seductive enough to move me from La Jolla to UCSB, but what had I gotten myself into? Initially, teaching was a jarring experience. Staying up late at night to prepare the next day's lecture interrupted my total focus on research. How could I compete with my peers at research institutions when half my time was occupied by teaching and administration, rendering me a half-time researcher? Granted, UCSB is a tier 1 research university, with high research expectations, but faculty peer pressure for excellence in teaching and a ratio of four undergraduate students to one graduate student (and very few postdocs) made for a very different atmosphere than that at research monasteries such as Scripps or Woods Hole.

After a long contemplative walk on the beach, it dawned on me that the only way to make my new job work both for me and for the students was to bring my research to the classroom, not just on behalf of my graduate students where the research-teaching connection is obvious but also on behalf of my science-phobic undergraduates. Halfway through my first stab at teaching oceanography for the masses, I was able to get a small education grant from UCSB to fly over Mt. St. Helens a few days after it erupted. The photos and 16-mm film of the smoking remains of once-beautiful Mt. St. Helens, which showed logging trucks tossed about like toys and thousands of acres of mature forest mowed flat, had the students on the edge of their seats. The Cascadia subduction zone had caused all this chaos, so from there it was easy to keep them engaged in learning the geometry of plate tectonics. Twenty years later, a freshman in my oceanography class told me that her mother, who was in my class in 1980, had never forgotten my Mt. St. Helens lecture and therefore had urged her daughter to take the class.

It was clear that I had to take every opportunity to inject research adventures into even the freshman-level classes. Diving in ALVIN to explore the deep ocean floor was another entree, seizing their attention long enough to present some of the more difficult aspects of mid-ocean ridge tectonics. I found that a good 1-min sea story could win me half an hour of rapt attention, so I tried to maintain that sequence, and it really worked. When discussing subjects well beyond my expertise, such as physical oceanography, I learned that drawing on first-hand research adventures of people I knew personally would also grab their attention. The students really like to know that their teacher is a doer, leading expeditions to the frontiers of science and bringing the excitement back to them, even before it is published and long before it appears in text books.

3 Bringing the Classroom to the Ocean

I encountered another obstacle that turned into a teaching opportunity. At UCSB we must teach at least one course every quarter. My colleagues in the Earth Science department were comfortable with doing their fieldwork on weekends or during the summer, but for seagoing oceanographers, the ship schedule spans 12 months a year, and, if you are lucky enough to be funded, you must go whenever you are scheduled. Only 1½ years into my new job as a professor, I had not yet accrued enough sabbatical time to permit me to be in the equatorial Atlantic for 6 weeks, and this was a sizable hiatus to put in the middle of a 10-week teaching quarter. Aha… why not make the entire expedition a course? Thus, Geological Sciences 181 (for undergraduates) and 281 (for graduate students) was born: GS 181/281 "Field Studies in Marine Geophysics" had sufficient units to be the only class a student would need to maintain full-time status. At least one department colleague felt that I was pulling a fast one, but the Chair and Dean were very enthusiastic. What an opportunity for the students to do exotic hands-on fieldwork with the National Science Foundation or Office of Naval Research picking up the tab! (This was long before NSF's program in Research Education for Undergraduates, or REU.) GS 181/281 presented an obvious opportunity for graduate students but could also be used to inject some excitement into my undergraduate classes. The top students in my undergraduate classes were eligible to apply to go on the cruises. Oh, that was another thing I had to figure out, never refer to my seagoing efforts as "cruises" as I had for years. My landlubber colleagues immediately conjured visions of a large comfortable "cruise" ship (>100,000 tons) with swimming pools and shuffle board courts and tropical evenings sipping gin and tonics as the sun set over the ocean, visions that were nothing like the small, distinctly uncomfortable ships where we worked 24/7 with no days off for many weeks. My seagoing research programs from now on would be referred to as "expeditions" that were available for class credit and were open only to the top scholars.

I began offering GS 181/281 in 1981. I assembled topical readers, which were a collection of research articles most relevant to the upcoming trip. We gathered twice a week before the expedition for classroom presentations of articles in the readers with differing perspectives on the hypotheses we would be testing at sea. We were about to embark upon a Deep Tow (tethered robotic vehicle from the Marine Physical Lab at Scripps) expedition to explore a deep gash in the seafloor known as the Vema Fracture Zone. This gash joins two segments of the Mid-Atlantic

Ridge and dates back to the separation of Europe and Africa from the Americas. An extensive suite of measurements was to be taken, including high-resolution topography (known as "bathymetry" underwater), side-scan sonar that provides acoustic images of the seafloor (which look a bit like grainy black and white photographs), magnetic field measurements, water temperature, and photographs. In addition, we would deploy arrays of sonobuoys to record real-time earthquake activity. The 12 undergraduate students and 4 graduate students flew to Charleston, SC, to join the ship, *R/V Gyre*. They didn't mind being crammed in 4 to a room and 8 to each bathroom. At sea, the seminar intensified with daily meetings addressing technical aspects of the equipment we were using and analyzing more advanced research articles. Coprincipal investigators, Drs. Jeff Fox, Kim Kastens, and Enrico Bonnati, added to the liveliness of the discussions and generously pointed out when they disagreed with me, much to the students' delight. In addition the students all served two 4-h watches per day, 7 days a week for 6 weeks. They were thrilled at the privilege and were in disbelief that they didn't have to pay for room and board! A win-win situation for all of us, they learned a great deal, and I was provided with eager watch standers for free. Everyone was exhausted but exhilarated by the time we departed from the Vema Fracture Zone for Fortaleza, Brazil. I was concerned as the students departed in groups, some to take side trips to Rio de Janeiro, the Amazon rain forest, or Machu Picchu, before the next quarter started. I was relieved to see all of them early the next term. I was also happy to see a proliferation of this teaching model among the marine scientists in my department and among other departments such as the Biology and Geography departments at UCSB. More UCSB students were getting the opportunity for hands-on oceanographic research. (It should be noted that Earth Science departments, at UCSB and many other universities, have a long-standing tradition of summer field geology and weekend field trips; what the new teaching model introduced was year-round access for students to work in the field for 1–2 months and opportunities to venture off-land to remote regions of the ocean.)

Based on the Atlantic expedition, which was such a success from the student's perspective, I offered the course the following year for work in the equatorial and south Pacific with port stops in Acapulco and Easter Island (Figs. 1 and 2). Needless to say I had no difficulty finding eager volunteers for this trip, and only the most outstanding students were able to go, 13 undergraduate and 6 graduate students. The intensive seminar format was the same in the weeks before and during the expedition. Added to the educational experience was a research project. Each group of three was to identify a focused question and use data gathered on the expedition to address it. There were many project choices, as this was the first Deep Tow expedition on the fast-spreading East Pacific Rise. Each student then wrote a paper on the results, due at the end of the quarter. Most had the papers written the day before we anchored off the south coast of Easter Island, as they were eager to embark upon even more exotic side trips on the way home than the Atlantic group had undertaken. They were also intrigued to find a Rapa Nui culture in 1983 that had little use for money but was eager to trade carvings and sculptures for denim jeans, tennis shoes, T-shirts, etc., the most prized trade object being a somewhat threadbare Jack Daniels baseball hat.

Fig. 1 Students and professors near Easter Island, 1983. Five of these students continued their studies to become professors and researchers at top institutions

Fig. 2 Students and professors in the South Pacific, 1988. Six of these students went on to become professors and researchers at top universities

Fig. 3 The author disembarking from ALVIN during the Rise expedition when “black smoker” hot springs gushing blackened hydrothermal fluids at 380 °C were first discovered on the East Pacific Rise near 21ºN. Students are inspired by these discoveries and are excited to know that their teacher was directly involved (RISE Team et al. 1980; Macdonald et al. 1980)

These expeditions had an infectious influence on subsequent classes I taught. Word spread that exotic seagoing opportunities were not just dreams but were well within their grasp if they worked hard in class. Even for those unable to go to sea, photos and videos of groups of students working together at sea, especially undergraduates, stoked an enthusiasm for the class material. I also tried to capture some of the excitement of these expeditions in articles approachable by the lay public, which were also assigned to my large classes (Macdonald and Luyendyk 1981; Haymon and Macdonald 1985; Macdonald and Fox 1990; Fox 1994; Lutz and Haymon 1994). The presence of students at sea also enhanced our research, not only in having a young eager team of watch standers but also by being surrounded by students full of questions.

The expeditions which generated the most excitement were those using the submersible ALVIN, which carries two scientists in addition to the pilot, is not tethered to the mother ship, and can dive to 4,500 m (Figs. 3 and 4). Dives typically last 8–12 h and are targeted to sites that are particularly promising based on prior mapping, sampling, and imaging efforts. Graduate students who had a stake in the research for their dissertations became scientific divers, while the undergraduates were inspired to excel in their studies so that they too might have this chance in the future. A large number of exceptional undergraduate exchange students from Leeds University and Royal Holloway University in the UK attended UCSB specifically to enroll in these seagoing courses. Several told me that they attended those two UK institutions over other,

Fig. 4 A 16-oz. milkshake cup (*right*) next to the same type of cup taken down to a depth of over 3,000 m outside of the submersible ALVIN, illustrating the great pressures at depth in a way that was very tangible to students

seemingly more prestigious universities, because of the exchange program with UCSB and the chance to go to sea. The at-sea seminars continued, with expeditions offered most years until 2006 when funding for deep-sea marine tectonics was reduced to a trickle. Ironically, NSF belatedly started the highly successful REU program only a decade before there were far fewer seagoing opportunities.

The future of deep-sea research is now centered on seafloor observatories (Ocean Observatories Initiative – Neptune) and on R/V Okeanos Explorer (NOAA's ship for ocean exploration). Both approaches allow for much greater remote participation via real-time feeds of video and remote "telepresence." The data gathered from both facilities are available for any scientist or student to analyze. As a retired oceanographer, the idea of sitting comfortably at home and seeing the latest in deep-sea exploration without the constant motion and often lousy cuisine is welcome. But for those young students, I wonder….Will staring at a video screen provide the same inspiration and excitement as heading out to sea on a ship to explore underwater regions no one else has ever seen? Or will the video experience seem somewhat slow motion compared to video games?

In order to avoid this possible source of ennui, it is crucial that students have the opportunity to go to sea and to participate in physical operations on deck such as launching and retrieving instruments and sampling devices. These activities are not at all inconsistent with some of the new exploration methods, such as Neptune or telepresence, but are complementary and will add to the engagement of all the students, even those who do not have the opportunity to go to sea. At least they will see their peers participating actively, which will stimulate their interest to pursue opportunities in oceanography.

Overview

Status Quo and/or Trends

- At research-intensive universities, professors rarely have any direct training in teaching.
- Teaching often is an imitation of the best of one's former teachers; however, more than this is needed to make course content compelling.
- Teaching is viewed as a separate activity from research and competes for limited time.

Challenges to Overcome

- Cuts in research budgets make it all the more difficult to combine teaching and research efforts and require more time spent on writing research proposals.
- Pressures to teach more classes make it difficult to find the time to compete for limited research funds effectively.
- The idea that teaching and research are separate and even competing efforts needs to be overcome.

Recommendations for Good Practices

- The best senior faculty should offer instruction and/or advice to junior faculty on effective teaching.
- Ways of effectively and symbiotically combining research and teaching efforts should be elucidated and encouraged.
- Opportunities for students to go to sea to participate directly in oceanographic research must be reinvigorated including physical activity on deck.
- For me, bringing the ocean to the classroom and the classroom to the ocean made me both a better teacher *and* a better researcher.

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Part III
Research-Teaching Nexus in Geoscience: Promoting Research-Enhanced Teaching

Curricula and Departmental Strategies to Link Teaching and Geoscience Research

Alan Jenkins

The research universities have often failed, and continue to fail, their undergraduate populations, thousands of students graduate without seeing the world-famous professors or tasting genuine research.

Boyer Commission (1998, p. 3)

"Teaching and research are correlated when they are co-related … [*One way to achieve this is to*] *exploit further the link between teaching and research in the design of courses."*

Brew and Boud (1995, p. 272)

The graduate skills that should be developed in (earth science) programmes are: … analysing, synthesising and summarising information critically, including prior research: collecting and integrating several lines of evidence to formulate and test hypotheses: applying knowledge and understanding to complex and multidimensional problems in familiar and unfamiliar contexts …

Quality Assurance Agency (UK) (2007, p. 5)

1 Introduction

How can individual faculty, course teams and departments effectively bring students into the worlds of geoscience research? How can faculty manage what can often be experienced as doing two 'separate' jobs – as a 'teacher' and a 'researcher'. In particular how can one devise curricula that effectively transform students' understandings of, and abilities to do research, and how can department strategies bring these worlds together to benefit students, faculty and the wider society. These are the issues developed here. The focus is mainly on undergraduate curricula for this is where the issues are most difficult to resolve – the links at doctoral level are more

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self evident, and undergraduate level is where most geoscience students study. The principles presented here are also directly applicable to (taught) postgraduate programmes and perhaps also to high school courses. In this chapter are interspersed brief case studies of examples of 'interesting practice' from geoscience and related disciplines. Readers are asked to use the case studies to make more explicit the general principles presented as stemming from the research evidence on teaching-research relations and to consider the relevance of the case studies to their own practice. Some readers may prefer to first skim read the case studies and then reread them in the light of the research evidence and general principles presented to explicitly link geoscience research and (university) curricula.

We start with a case study from an internationally recognised research university where the strategy focuses on those informal aspects of departmental culture which potentially can bring students into the worlds of geoscience research, or keep research and researchers being closed doors.

Case Study 1: Earth Sciences at Oxford University, UK

> Fieldwork is a central aspect of Geology and, almost irresistibly, it imposes a flavour upon our teaching. … A day in the field typically involves more than 12 hours of close-contact teaching, in which the agenda is set by the observations that the students make, and the questions that they pose. Frequently, those questions have no known answer. …
>
> The informality engendered in field teaching cannot be erased or forgotten back in Oxford. By the time they are in their second year, most undergraduates are on first-name terms with the academic staff …. A variety of practices underpin this informality in ways that, separately, do not appear particularly powerful but which, because they are valued by all, have a large cumulative effect. Interaction space is highly valued, and it is an (unwritten) guiding principle that anyone can interact with anyone else in the common space (library, staff coffee room, undergraduate common room, etc.). (England 2007, pp. 9–10)

This case study illuminates one aspect of how disciplinary concerns and practices shape teaching-research links in the geosciences – the curricula potential of fieldwork where students can experience something of the complexities of research and can themselves be active in learning something of that complexity. It also speaks to the importance of deliberating shaping the culture and the practices of the department to explicitly bring students into research as a disciplinary community of practice (*Northedge and McArthur* 2008).

The next case study is a more structured way of doing this and is explicitly focused on students understanding the nature of research done by the faculty teaching them. Again this is a case study from a strong research department where all the faculty are involved in high-level research. As you read it consider how it might be adapted to a department where only selected staff are involved in high-level research.

Case Study 2: Geography Students Interview Staff About Their Research at University College London (UCL), UK

All year 1 students do an assignment in term one, in which students interview a member of staff about their research:

- Each first-year tutorial group is allocated a member of staff who is not their tutor.
- Tutorial groups are given three representative pieces of writing by the member of staff along with a copy of their curriculum vitae and arrange a date for the interview.
- Before the interview students read these materials and develop an interview schedule.
- On the basis of their reading and the interview, each student individually writes a 1,500 word report on (a) the objectives of the interviewee's research, (b) how that research relates to their earlier studies, (c) how the interviewee's research relates to his or her teaching, other interests and geography as a whole.

Source: Dwyer (2001)

Note also how in this UCL case study the focus is on students in their first term in year 1. To be critical much discussion of teaching-research links centres on student research projects in their final year. Such are very important and are the focus of a current project led by Mick Healey (http://insight.glos.ac.uk/tli/activities/ntf/creativehops/Pages/default.aspx).

However, the research evidence is clear: many students in many departments fail to see the relevance of a research focus to their courses and the potential importance to them of faculty involvement in research. This UCL course seeks to help year 1 students better appreciate the importance to them of the research done by the faculty teaching them. As to the challenge I posed as to whether this could be adapted to a department where only selected faculty were involved in research, one 'answer' might be that it can't. It reflects the particular opportunities and difficulties of managing at departmental level these two different roles in a 'research-intensive' department/institution. Alternatively you might see ways of adapting it to a different departmental culture – e.g. students in teams interviewing staff in a local geoscience-based company as the extent to which their work involves an understanding of/contributes to current research in the geosciences.

2 The Research Evidence Summarised

There is a developing research literature on teaching-research relationships in higher education, and a variety of research methodologies have revealed the complexities of these relationships (Jenkins 2004; Healey and Jenkins 2009). In summary this research reveals:

- Studies of the attributes of individual faculty reveal a very limited correlation between their qualities as teachers and researchers.
- Qualitative research on the student experience reveals that undergraduate students are often unaware of/feel excluded from the worlds of university research.
- Faculty experience tensions between their roles as teacher and researcher.
- National, institutional and departmental *research* policies often ignore the potential of developing undergraduates' understanding of research.

- While there are often interesting curricula examples that explicitly bring teaching and research together, these are seldom explicitly developed through a degree programme.
- Research on the impact of various forms of inquiry-/research-based learning has shown the potential of these curricula forms on student intellectual development.
- Some research emphasises how teaching-research relations are shaped by the nature of research and pedagogic practices in particular disciplinary communities. In the case of earth sciences, Thomas (2003, p. 11) points to the curricula importance of the final year mapping exercise that has long shaped (UK) earth science departments and how geoscience research has shifted from 'an observational science (traditional 'Geology') to a multidisciplinary science'. While, as observed above in the discussion of the Oxford Uuniversity Earth Sciences Department, intensive geoscience field courses offer the potential to make the students experience of the curriculum in part an entry into the complexities of geoscience research.

One central review of the research evidence concluded that 'the fundamental issue is what we wish the relationship to be, and we need to devise policies to enhance this wish … (and that to better ensure effective teaching research links) *we need to increase the skills of staff to teach emphasising the construction of knowledge by students*' (Hattie and Marsh 1996, pp. 533–534, emphasis added).

For many of us the relationship we wish to develop is that in universities students are brought to higher levels of intellectual development through their understanding of the complexities of knowledge and that students develop this understanding in part through learning through some form of research or inquiry appropriate to their discipline(s). Furthermore pragmatically developing effective teaching-research relations help institutions, departments and individual faculty 'manage' teaching and research roles, which otherwise can too easily conflict including over the time and other resources to undertake these roles.

Case Study 3: Special Programmes for Selected Students?

Given the costs of providing research opportunities for all students and sometimes a view that only the most able students benefit from involvement in (faculty) research, one strategy is to restrict such opportunities to the most able/committed students.

This is the approach of the many 'undergraduate research' programmes in the USA and now increasingly elsewhere internationally. Typically such programmes offer special opportunities for selected students to carry out research with or closely supported by selected faculty. For example, each year the Keck Geology Consortium of liberal 'arts' universities sponsors approximately 50 undergraduate students in a wide variety of geological/environmental science sub-disciplines and locations. The programme includes 4 weeks of summer research (field and/or lab work depending on the project), continuing research during the academic year (jointly advised by a project faculty member and a research advisor at the students home institution), attendance at the annual Keck Geology Consortium Symposium and a publication in the annual Keck Geology Consortium proceedings volume. Students receive a $1,500 stipend, and typically all travel and living expenses are provided (http://keckgeology.org/students).

Many of these programmes are organised and funded at departmental level and operate as special disciplinary summer programmes. Major research funders nationally may well fund selected students as does NASA's Planetary Geology and Geophysics Undergraduate Research Program (http://www.acsu.buffalo.edu/~tgregg/pggurp.html).

The (US) Council on Undergraduate Research Geoscience Division provides a range of resources to support such programmes (http://www.personal.psu.edu/uxg3/blogs/geocur/).

3 A Framework for Curriculum Design and Teaching and Research Links

The above research has indicated the complexities of teaching-research relations. It has also stimulated a range of investigations and interventions to help better bring teaching and research together. One development has been a more sophisticated understanding of what departments and disciplinary communities might mean by 'linking teaching and research'. You can use the framework below both to interrogate your own practice and to 'review' many of the other chapters in this book.

Curricula can be:

Research-led: *Learning about current research in the discipline*. Here the curriculum focus is to ensure that *what* students learn clearly reflects current and ongoing research in their discipline. This may include research done by faculty teaching them.

Research-oriented: *Developing research skills and techniques*. Here the focus is on developing students' knowledge of and ability to carry out the research methodologies and methods appropriate to their discipline(s).

Research-based: *Undertaking research and inquiry*. Here the curriculum focus is on ensuring that as much as possible the student learns in research and or inquiry mode. The strongest curricula form of this is in those special undergraduate programmes for selected students, but such research and inquiry may also be mainstreamed for all or many students.

Research-tutored: *Engaging in research discussions*. Here the focus is on students and staff critically discussing research in the discipline as, for example, in many seminar-based courses (Healey and Jenkins 2009).

These are shown in Fig. 1.

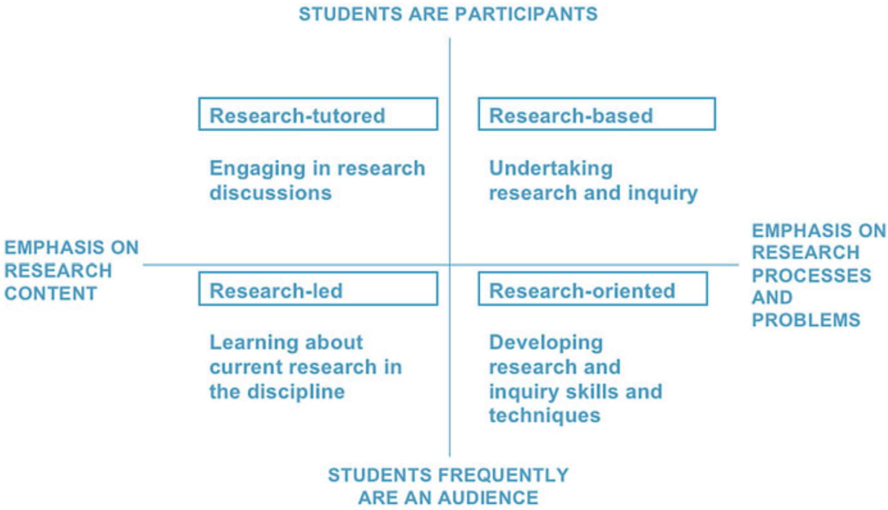

Fig. 1 The nature of undergraduate research and inquiry (Source: Healey and Jenkins 2009, p. 7)

This model, slightly amended from the one in Healey (2005), has two axes, one classifies the ways students may be engaged in research and inquiry according to the extent to which students are treated primarily as the audience or as participants, while the second axis classifies the approach as emphasising research content or research processes and problems.

The four ways of engaging students with research and inquiry are not independent. Thus, if you use this framework to analyse the case studies included in this chapter, you will see that many courses contain elements of more than one approach. For example, looking back at Case Study 2 of geography at University College London, in one way it is clearly *research-led* in that it is clearly based around current research by the faculty teaching the students. Yet from another perspective, it is *research-based* in that students are inquiring within a research framework designed by staff.

All four ways of engaging students with research and inquiry are valid and valuable, and curricula can and should contain elements of them all. So the question becomes not so much 'Do you engage your students in each of these ways?' as 'What proportion of their time do they spend in each category and is this an appropriate balance given the students you teach, the type of course and discipline and the departmental and institutional culture?' We argue that in much of higher education, too much teaching and learning is in the bottom half of the model, i.e. the student as an 'audience', and students would benefit from spending more time in the top half, i.e. as participants in research. This framework provides a language to discuss such issues. It can be used by individual faculty to analyse their own courses, and more powerfully it can be used by course teams and departments to analyse practice across a range of courses from year 1 to graduating year.

The next two case studies focus on the students' entry into their degree in year 1 and address the 'challenges' of bringing a research approach to large (introductory)science courses where the costs of student access to laboratories and science equipment present particular problems to adopting a research or inquiry approach to curriculum design.

Case Study 4: At Cornell University, USA, All First-Year Biologists Have Research Experiences

The 'Explorations Program' introduces biology first-year undergraduates to research by Cornell staff, in the context of a course of 700–900 students. Large-scale funding has created 100–120 'experiences', each of approximately 3–4 h, for groups of 6–8 students. Most are designed to introduce students to the kinds of research problems on which the academic staff member works. Programmes take place both in research labs on campus and at field sites near campus. Each student is required to participate in one 'Exploration' per semester. For example, recent explorations have varied from 'fossil flowers of the dinosaur age' to 'why do sperm swim in circles?'

Sources: (http://www7.miami.edu/ftp/ricenter/Spotlights/spotlight.html; http://biog-1101-1104.bio.cornell.edu/BioG101_104/explorations/explorations.html)

Case Study 5: Inquiry-Based Learning (or 'SCALE-UP') in Introductory Science Classes

SCALE-UP, or 'Student-Centered Active Learning Environment for Undergraduate Programs', has been widely adopted and adapted in a wide range of US universities across a range of science disciplines.

The basic idea is of a radically redesigned classroom and linked web-supported learning environment. The traditional lecture and linked laboratory format is replaced by '4–6 hours of activity based instruction per week, typically in 2-hour blocks' (Beichner et al. 2007, p. 3). Students work in groups at round tables with web support and white boards. 'Most of the class time is spent on 'tangibles' and 'ponderables'. Essentially these are hands-on activities, simulations, or interesting questions and problems. There are also some hypothesis-driven labs where students have to write detailed lab reports' (http://scaleup.ncsu.edu/FAQs.html).

These case studies bring out how large introductory and laboratory classes can involve students in controlled research studies. While individual faculty can introduce aspects of these approaches to their courses, they demonstrate the importance and indeed the necessity of departmental funding and planning. Indeed aspects of them – e.g. timetabling – may require institutional support, and such large-scale funding will benefit from both institutional and national funding. These case studies in effect challenge departments and institutions as to what is/are their central function(s)? For myself and I think the challenge of this book that includes a central concern to bring students into an understanding of the complexities of the world revealed through research. If that is accepted, then strategies such as these two case *studies reveal the necessity of carefully designed and well-funded departmental strategies to bring teaching and research together*.

4 Curricula Strategies for Effective Teaching-Research Links

In presenting this approach to course design whether by individuals, course teams or departments, I recognise that ensuring teaching-research links is but one aspect that needs to be considered in designing courses. Elsewhere I have likened designing courses to controlling an Ouija board (Jenkins 2009) where the curriculum is shaped by a variety of forces, including the nature of the discipline, the overall resources available, the university regulations and requirements, the need and the pressures to support student employability and, as is argued here, the shaping of teaching-research links. The focus on supporting teaching-research links is partly for reasons of faculty and student motivation but ultimately because the teaching-research nexus should be what distinguishes *higher* education from high school or vocational education. Many argue that this ideal is not only critical for ensuring that what the students experience is *higher* education; it is also important for subsequent employability. Thus, Scott (2002, p. 13) has argued:

> We are all researchers now … Teaching and research are becoming ever more intimately related … In a 'knowledge society' all students – certainly all graduates – have to be researchers. Not only are they engaged in the production of knowledge; they must also be educated to cope with the risks and uncertainties generated by the advance of science.

Many geoscience students after graduation enter careers where the science is complex and contested and where its application to society is likewise complex. Their curricula need to prepare them for that complexity. The following principles have been developed through analysing (and contributing to) the research evidence on teaching-research relations and through analysing many disciplinary case studies of practice and policy including those presented here. I offer them for you to consider their relevance to your individual courses and to support course team and departmental discussions and decisions.

5 Strategies for Linking Teaching and Research Within Courses and Programmes

Strategy 1: Develop Students' Understanding of the Role of Research in Their Discipline(s)

- Develop the curriculum to bring out current or previous research developments in the discipline.

- Develop students' awareness of learning from faculty involvement in research as in the case of geography at UCL (Case Study 2).
- Develop students' understanding of how research is organised and funded in the discipline, institution and profession.

Strategy 2: Develop Students' Abilities to Carry Out Research

- Students learn in ways that mirror research processes as, for example, in many geoscience fieldwork programmes.
- Assess students in ways that mirror research processes for example requiring students to have their work assessed by peers according to the house style of a journal before submitting it to you (Case Study 6).
- Provide training in relevant research skills and knowledge.
- Ensure students experience courses that require them to do research projects and that there is a progressive move to projects of greater complexity.
- Develop student involvement in faculty research.

Strategy 3: Progressively Develop Students' Understanding

- Ensure that introductory courses induct students into the role of research in the earth sciences and present knowledge as created, uncertain and contested. This principle is well demonstrated in Case Studies 4 and 5 of biology at Cornell and SCALE-UP.
- Ensure that advanced courses develop students' understanding of research and progressively develop their capacities to do research.
- Ensure that graduating year courses require students to carry out a major research study and help them to integrate their understanding of the role of research in their discipline or interdisciplines, and perhaps prepare them to bring that research understanding to future employment.

Strategy 4: Support Students Think to Beyond Disciplinary Research Silos

- Bring out the different research methodologies within the earth sciences and the different research methodologies 'favoured' by the individual faculty in the course team.
- Develop student awareness that much research in the geosciences – and certainly its application in employment and society – is in effect interdisciplinary (Committee on Facilitating Interdisciplinary Research, National Academy of Sciences, National Academy of Engineering, Institute of Medicine 2004).

Strategy 5: Manage Student Experience of Faculty Research

- Limit the negative consequences for students of faculty involvement in research. Most important here is managing the student experience of the days (and sabbatical terms) when faculty are 'away' doing research.
- Evaluate students' experience of research and feed that back into the curriculum.

- Support students in making clear to them the employability elements of research. This is particularly important for those students whose focus is on using a degree to get employment and who may not otherwise appreciate the value of a research-based approach.

Case Study 6: Academic Journal Writing as Part of Course or Programme Requirements (Geography at Oxford Brookes, UK)

The geography programme at Oxford Brookes has developed a set of linked programme requirements that support all students learning to write research articles. In the second year all students undertake field-based research in a range of venues. A third (final) year compulsory first semester course 'Geography Research and Practice' has as its main aim 'to develop your skills in writing scholarly reports of your own research'. The one assessment is for students to 'write an article of up to 4,000 words from the data that you collected in your (second year) fieldwork. The article will conform to existing academic practice for the preparation and submission of scholarly work'. Relatedly the department has also just initiated an undergraduate e-journal *Geoversity* (http://www.brookes.ac.uk/schools/social/geoversity/index.html) to publish selected 'high-quality' articles by students in the department including articles that were originally written for the module 'Geography Research and Practice'. In addition some students take that experience/expertise to revise their article, or the research for their capstone dissertation for publication in the departmental undergraduate research journal *Geoversity*, or even in the linked newly established national geography e-journal *Geoverse* (Walkington 2008).

This case illustrates how a set of structured interventions by the whole course team through a degree programme supports students growing abilities as researchers. In addition the emphasis on students writing journal articles is an example of how the form of student learning relates to how many faculty disseminate their research. Relatedly many science courses now require students to present their inquiries in the form of a poster, and the class session takes on the form of a conference – similarly to how many faculty present their research at academic conferences. The use of posters and student conferences is a feature of Case Study 7 Earth sciences at McMaster.

6 Strategies for Departments

Many of the suggestions above have been developed by individual faculty and course teams. All will have more impact if they are part of a coherent design by departments (and ideally institutions and national systems, including professional associations). Here the roles of Heads of Department and senior faculty are central to their development and effectiveness.

The first two case studies of geology at Oxford University and geography at University College London are examples of department-level strategies as is the one below from McMaster.

Case Study 7: Integrating Inquiry and Research Skills Through a Whole Degree Programme (Geography and Earth Sciences at McMaster, Canada)

In Level I, the development of inquiry and research skills begins in courses where students are introduced to inquiry-based learning through the use of a Socratic, 'questioning style' of lecturing and lab assignments that require students to formulate and answer their own research questions.

Many Level II and III courses involve students in short-term (several weeks) independent or team research projects. Students present the results of their research as a written paper, a poster or an oral presentation.

In Level IV, all students are required to undertake some form of individual research project, either as a one-term (13 weeks) research paper or as a full-year (minimum 26 weeks) undergraduate thesis.

In undergraduate research, many thesis students are employed as research or field assistants by faculty during the summer months or on a part-time basis during term time. McMaster University hosts an Undergraduate Research Poster Session each year, and many undergraduate students are encouraged to present the findings of their research at national or international conferences and to submit manuscripts (co-authored with their research supervisors) for publication in scientific journals (Eyles and Vajoczki 2009).

Despite these examples of 'good practice', the research on departments suggests that too often teaching and research are often treated as separate activities. Thus, Coate et al. (2001, p. 162), in a study of departmental organisation in the UK, showed that departmental managers found that '… it is more convenient for teaching and research activities to be treated as separate activities. On an academic level, however, managers would rather perceive the two to be synergistic'. Such research has stimulated a range of interventions and recommendations to more effectively link teaching and research. The following questions developed out of a UK project to more effectively integrate teaching and research in built environmental disciplines. They provide a set of questions to shape discussions and strategies at department level.

- What is your departmental and disciplinary understanding or conception of 'research-led', 'research-based' or 'research-informed' learning?
- What forms of pedagogy and their assessment do you consider appropriate to support these conceptions?
- Can you clearly identify where research-based learning is integrated in the programme?
- Where is current research in your field presented in the programme? How does research relate to programme design and programme outcomes, curriculum content and delivery in the modules and assessment methods?
- Where are research methods, skills and ethics taught and practised? Is this progressive? Is a variety of appropriate skills and methods delivered?
- Are the research knowledge and skills the student will have acquired made clear in the module learning outcomes?
- Can and do students participate in departmental research projects as, e.g. research assistants?

- Where is the scope for students to conduct independent research in their programmes and in what ways do the programmes allow progression?
- How are research skills and the links between teaching and research embedded in monitoring and review of modules and programmes?
- How are students supported in making explicit how this research training and knowledge increases their employability?
- How are undergraduate students made aware of postgraduate research opportunities?
- How does the department's research strategy explicitly support (undergraduate) students learning through and about research?

Source: Based on Jenkins et al. (2007, p. 59)

7 Conclusions

For many of us, what distinguishes higher education is the student learning through and about research. Yet, the research evidence suggests that this is often not achieved in practice and policy. However, there are now internationally in the earth science

Overview

Status Quo and/or Trends

– For many academics in all disciplines, what distinguishes higher education is the student learning about and through research and or inquiry.
– However, the move to a mass higher education system and the importance attached by national systems and research funders to high-level 'discovery research' threatens the close connection between faculty research and undergraduate student learning.
– While these issues are generic across all disciplines, the nature of geoscience research and the geoscience curriculum may shape the importance and nature of teaching-research relations in the geosciences.

Challenges to Overcome

– Recognising the growing research evidence that generally shows that the close connections between teaching and research that is so often professed by academics and departmental websites are too often not realised in practice and policy.
– Recognising that students, particularly those with a strong interest in employment outside academia, will need to be convinced of the value of teaching closely linked to research.

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Recommendations for Good Practices

- Course teams and departments need to systematically develop teaching-research links through courses and programmes.
- Make how the student learns and is assessed as close to the way faculty in earth science carry out and disseminate research including links to industry.
- Make clear to students the value of a research approach both to their intellectual development and to future employment in earth science related and other forms of employment.
- Attention needs to focus on both the teaching and the research strategies to achieve these potential links.
- Seek out and reshape to meet your needs the growing examples of 'interesting practice' in earth science curricula and departmental strategy that have sought to achieve effective teaching-research links.

and related disciplines a range of structured interventions by individuals, course teams, departments and national scientific organisations that demonstrate how these links can be achieved. They and the other chapters in this book offer examples and principles for others to adapt to their particular contexts.

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The Role of Scholarly Publication in Geocognition and Discipline-Based Geoscience Education Research

Julie Libarkin

1 Introduction

Publication plays an important role in scholarly discourse. The growth and decay of domains of inquiry can be observed within the pages of our academic journals. The development of new fields, such as genomics or neotectonics, may be documented explicitly (Odum 1977) or may simply become part of normal discourse as journal publications and presentations at professional conferences reflect new scholarship (Good 2000).

Science, technology, engineering, and mathematics (STEM) fields have seen the rapid growth of discourse related to education that comes from STEM scholars, rather than from the more traditional domain of science education. Generally, science education scholarship emerging from the STEM fields is known as Discipline-Based Science Education Research, or DBER. Within the USA, professional organizations are beginning to explicitly discuss the nature of DBER scholarship and faculty positions within the disciplines. For example, the US National Research Council has held three events to explicitly discuss DBER within STEM.

The first event was the Workshop on Education Research Positions in STEM Disciplinary Departments, held in 2005. This first event brought together faculty from across STEM fields in a discussion of the motivations, purposes, and institutional structures for DBER positions within STEM departments. This workshop produced a number of reports, including one that described the state of DBER in geosciences.

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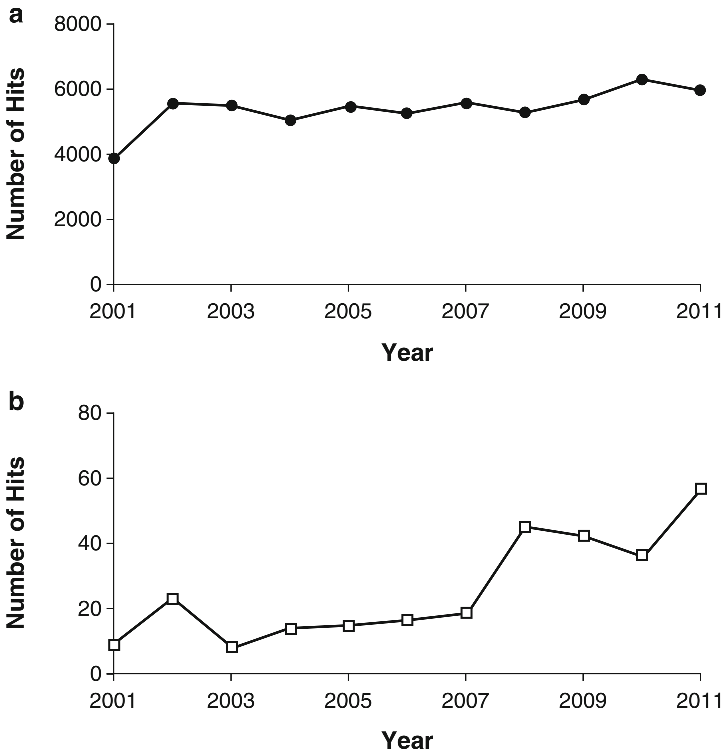

Fig. 1 Presentations related to (**a**) "education or teaching or learning" and (**b**) "cognition or geocognition or cognitive" at the US Geological Society of America meetings from 2001 to 2011

The second event, a two-part workshop held in 2008, brought together scholars from across STEM to discuss promising practices in STEM education (http://www7.nationalacademies.org/bose/PromisingPractices_Homepage.html). This included discussion of curriculum and assessment emerging from the geosciences. The third event, a 30-month study in 2010–2011, was designed to guide DBER research directions (http://www7.nationalacademies.org/bose/DBER_Homepage.html). This effort was intended to encourage colleges and universities to increase DBER research activities, utilize DBER research in teaching and assessment for student learning, and consider the influence of instruction on student attrition in natural science.

Clearly, DBER has emerged across STEM and certainly within the natural sciences. The status of research focused on teaching and learning in geoscience classrooms or other educational settings (geoscience education research) and research focused on how people perceive and understand the Earth (geocognition) as emergent domains of scholarship is also fairly clear. Analysis of presentations at all US Geological Society of America (GSA) meetings held since 2001 illustrates domain emergence (Fig. 1). A search of the terms "education or teaching or learning" yielded several thousand hits per year since 2001, suggesting significant discourse about education among geoscientists. Education-related talks or sessions are about 100 times more frequent than those that are cognition related; geocognition work experienced a sixfold increase between 2001 and 2011.

In general, the majority of presentations on "geoscience education" at GSA are pedagogical in nature, while "geocognition" presentations tend to be research oriented. The division between pedagogy and research can be murky, although I would argue that geoscience education research is a subfield within geocognition, where geocognition covers any cognitive, affective, or psychomotor process that relates to human interaction with the Earth, and geoscience education is the specific sub-case of human interaction with the Earth in explicit educational settings (Libarkin 2006). Some interesting examples of geocognition research can be found in a special publication of the Geological Society of America, *Qualitative Inquiry in Geoscience Education Research* (Stokes and Feig 2011).

2 Journals

Publication of geocognition research occurs in a diverse set of journals. Most familiar to US geoscientists is the *Journal of Geoscience Education* (*JGE*), for which I was Editor-in-Chief for 3 years from 2009 through 2011. A wide variety of other journals of importance exist, particularly as we consider the settings beyond "education" in which geocognitive research can occur.

Eighteen journals provide an opportunity for specifically geoscience research related to teaching, learning, and cognition (Table 1). In this context, I have included journals from geoscience proper, as well as journals that explicitly publish in environmental or geography education and cognition. Although many cognitive

Table 1 List of journals targeting scholarly publication in geocognition

Pedagogical journals	Research journals
Australian Journal of Environmental Education	Applied Environmental Education and Communication
Canadian Journal of Environmental Education	Environmental Education and Information
The Earth Scientist	Environmental Education Research
Geology Teaching	International Electronic Journal of Environmental Education
In the Trenches	International Journal of Environmental and Science Education
New England Journal of Environmental Education	International Research in Geographical and Environmental Education
Planet	Journal of Environmental Education
Teaching Earth Sciences	Journal of Geography in Higher Education
	Journal of Geoscience Education
	Philosophy & Geography

Division into "pedagogical" and "research" categories is by primary emphasis

"Geography" includes geosciences in some countries

Environmental science education journals (in regular font) can be appropriate venues for publication of geosciences-related work science journals publish geoscience work, no journal specific to geocognition exists. Eight of the seventeen identified journals are primarily pedagogical in nature, encouraging the sharing of resources for effective instruction in geoscience, environmental science, or geography. The remaining ten journals have a more explicit focus on research, although pedagogical papers containing evidence of effectiveness are generally welcomed. Finally, readers should be aware that many journals of interdisciplinary interest have published work in geocognition, including as limited examples *Journal of Research in Science Teaching* (Lewis and Baker 2009), *Research Papers in Education* (Trend 2005), *Topics in Cognitive Science* (Forbus et al. 2011), *Cognition* (Kelemen and Rosset 2009), *Journal of the Learning Sciences* (Hmelo-Silver et al. 2007), and *Learning*, *Media and Technology* (Lin et al. 2011).

2.1 The Journal of Geoscience Education

The Journal of Geoscience Education (*JGE*) and the *Journal of Geography in Higher Education* are perhaps the most cited journals within the field. The latter journal serves a much more global community than the former, although *JGE* is moving to increase its international reach.

My tenure as Editor-in-Chief represented a significant transition for *JGE*. The US National Association of Geoscience Teachers (NAGT) began publishing *JGE* in 1951 under the title *Journal of Geological Education*; the name changed to *Journal of Geoscience Education* in 1996. *JGE* originally served as the communication venue for NAGT. This communication took the form of research papers, as well as columns, editorials, meeting reports, and awards announcements. As the community of DBER researchers in geoscience grew, the need for a journal dedicated to publishing scholarship in geocognition and geoscience education research became obvious.

JGE transitioned to a scholarship-only journal in late 2009; NAGT began publishing a magazine in 2011 as an outlet for NAGT news and informal discussion of ideas. The transformation of *JGE* began with the development of guidelines for submissions. These guidelines were reviewed and revised by *JGE*'s Associate Editors, with their adoption by the Journal in Fall 2008. This allowed publication of manuscripts that met “old” guidelines through most of 2009, while simultaneously handling new manuscripts reviewed under the “new” guidelines. The first issue to publish articles written and reviewed under the new guidelines occurred in 2009 with a Special Issue on Thinking and Learning in the Geosciences (http://nagt-jge.org/resource/1/jgeoe5/v57/i4). This issue exemplifies the commentaries, curriculum and instruction, and research papers that can now be seen within *JGE*'s pages.

My experience as Editor has been eye opening and suggests that geocognition is a growing field. I have been exposed to scholarship that reaches far beyond my personal expertise. The work being undertaken by the geocognition community is far ranging, with incorporation of methodologies from far-flung fields, for example, the pages of *JGE* host articles incorporating ethnography (Feig 2010), ontology (Libarkin and Kurdziel 2006), and spatial cognition (Titus and Horsman 2009) into the study of how people perceive and understand the Earth. Roots of this type of scholarship stretch back to *JGE*'s earliest days, although the community is now much more explicit about the norms expected of papers published under peer review, as well as the diversity of communities that are making valuable contributions to the field.

3 Publication as Discourse

Journals have always played an important role of documenting the norms of the communities they serve. Journals are also a record of the interactions between communities publishing different journals. An analysis of all articles published in *JGE* in 2009 offers insight into the nature of communication within and outside of the US geoscience education community, as well as directions for future change.

In 2009, articles published in *JGE* referenced 927 publications, including 595 journal articles published in 118 different journals (Fig. 2). The community publishing in *JGE* references other closely relevant journals in just under 25 % of references, including international journals (e.g., *Journal of Geography in Higher Education*), cross-disciplinary journals (*Philosophy & Geography*), and local magazines (e.g., *Planet*). In addition, *JGE*'s authors incorporate lessons from literature emerging out of many fields (Fig. 2). Over 45 % of journal references are to journals

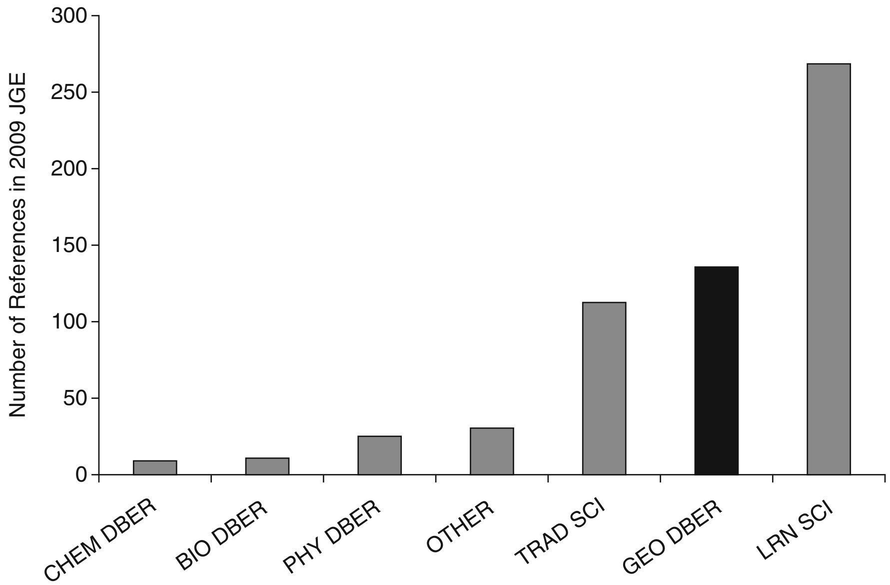

Fig. 2 Range of domains referenced by articles ($n=595$) published in the *Journal of Geoscience Education* (*JGE*) in 2009. DBER refers to Discipline-Based Education Research, where CHEM, BIO, PHY, and GEO are chemistry, bioscience, physics, and geoscience, respectively. TRAD SCI refers to articles, typically not related to education or cognition, published in traditional science journals. LRN SCI are journals housed in the education, learning science, or cognitive science domains. OTHER represents journals that fall outside of the previous categories

within education, learning science, and cognitive science; another 8 % are to DBER in other science disciplines. This pattern of referencing indicates that (1) geocognition research has its own community, engaging in conversations within its own journals, and (2) the community values the discourse of “ancestral” fields such as science education and cognitive science. The limited referencing of DBER emerging from other sciences is noteworthy, although similar analysis of other DBER journals indicates that the geosciences are the most transdisciplinary of the STEM communities engaged in science education, learning science, and cognitive science research.

4 Future Directions and Recommendations

Scholars engaged in cognitive science, learning science, or education investigations within the geosciences have a defined set of journals within which they can publish (Table 1) and expect to be communicating with peers. Certainly, publication of geocognition research outside of the geosciences is important, particularly if we want to bridge communication gaps with other communities.

Scholars engaged in geocognition face a unique challenge. Three distinct communities need to be made aware of research findings, and these communities generally do not read the same journals. First, the scholars engaged in similar work within the community must be reached. This requires publication within community journals, such as those in Table 1. Second, scholars in other science DBER, the general STEM education, and learning science communities will benefit from work emerging from within our community. Certainly, a study of the role of, for example, inquiry-based activities on student learning in geoscience is likely of importance to scholars studying inquiry learning, regardless of their field. Finally, geoscientists in general need to be made aware of our findings. This is the most difficult community to reach and the most pressing. Certainly, my own scholarship may have implications for the nature of expertise that can influence the practice of geosciences itself (e.g., Hambrick et al. 2012) or is working to build a community of faculty engaged in best practices in assessment (e.g., Libarkin et al. 2011). Other scholars are engaged in work of equal value to either the professional or teaching geoscientist or both.

How to best communicate with our larger geoscience community is still unclear. Publication in leading interdisciplinary journals, such as *Science*, is possible, setting an example for our disciplinary colleagues. High-quality geocognition research, as a representation of work emerging from a new domain within the field of geosciences, should be published in our larger community’s journals (e.g., *Geology*). As the field expands, we must ask ourselves: How do we ensure that geoscience journals can recognize high-quality geocognition research? This recognition will likely only occur with interdisciplinary communication with the non-geoscience fields that have influenced norms and values of geocognition. These fields, including DBER, education, learning science, and cognitive science, are not traditional partners for geoscientists; effective collaboration will require cultural shifts that are already beginning. Certainly, interdisciplinary publication may be made more difficult given the realities of how journal publication is valued. For many scholars, only publication in high-impact journals is of value to career success. Interestingly, the more communities that cross-reference one another, the greater the impact of any individual journal; therefore, it would benefit all journals to encourage authors to reference interdisciplinary scholarship. In essence, effective communicating about geocognition requires communication among many disciplines both within and outside of the geosciences.

Overview

Status Quo and/or Trends

- Discussion of education has a long history and significant presence within the geoscience community.
- The community houses a number of journals in which we can and do publish.
- Referencing rates indicate that we value work emerging from other related fields, particularly education, learning science and cognitive science.

Challenges to Overcome

- In the United States, the community of geocognition researchers has only recently established norms for publication within the premier journal, *JGE*.
- Referencing rates within the journal suggest disconnects between the geosciences and other STEM fields engaged in DBER research.
- Opportunities to publish in more general geoscience journals are quite limited.

Recommendations for Good Practices

- Scholarly findings in geocognition need to be communicated to the geoscience community at large.
- Careful attention should be paid to ensuring that work published in general geoscience journals is of the highest quality. This requires interdisciplinary communication.
- Communication with fields of education, learning science, and cognitive science is in its infancy, but holds promise for ensuring the highest-quality geocognition and geoscience DBER work possible.

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Geologic Displays as Science and Art

Marjorie A. Chan

1 Introduction

1.1 Goals of the Educational Environment

Many universities have a long-term goal to make their campus more vibrant and engaging, to create a "signature experience" for students. This aim is becoming more important in view of the online classes and degrees and the fact that students spend less and less physical time on the campuses. This chapter focuses on how implementing imaginative designs in the built environment can transform an academic campus building into an interactive, museum-like destination for visitors and students, one that engages, teaches, educates, and inspires. This is a collaborative, sustainable, and synergistic approach to seamlessly integrate visual and tangible elements that represent an academic discipline. At its best, a welcoming environment can become a highlight of the campus, transform campus expectations, integrate teaching and research, be a recruitment tool for faculty and students, and serve as a community resource that raises visibility and stimulates broad interest in Earth science.

1.2 Earth Science Perspective

Studies show that museum-type exhibits with visual artifacts can enhance the traditional classroom learning (e.g., Flexer and Borun 1984; Allen 2004). They provide "satisfying experiences" and a restorative environment, which enables visitors to relax

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and recover from the stresses of life (Packer 2008). Other articles (e.g., Ramey-Gassert et al. 1994) examine the new emphasis on museums to partner with schools and colleges to enhance science literacy. Museum-type settings provide opportunities for students to be active participants in learning by manipulating or touching objects in a stimulating setting, thus enhancing conceptual learning (Hooper-Greenhill 2007). These engaging components of learning are important for understanding complex science concepts and introducing visitors to the many and varied forms of a discipline that may be difficult to experience elsewhere (Talboys 2010).

Fortunately, Earth science is a field that has intriguing, visual material that exemplifies the discipline and can be displayed by museum-like exhibits within academic, campus buildings. Landscape art has beautifully expressed geologic themes for centuries, and interest in combining artistic approaches has been successfully used to teach geologic concepts (Tobisch 1983; Chan 1993; Rosenberg 1997, 1998, 2000; Friedman 2009). A compelling exhibit of geologic materials entitled "Fossil Art," assembled by Adolph Seilacher (Seilacher 1997), showed how well-lit rocks and fossils can be considered art in their own right. Natural materials have a lasting and timeless beauty of their own that transcends traditional boundaries of cultures and ages.

Informative geologic displays may increase inquiry on a simple level to truly raise awareness of Earth science literacy (National Science Foundation ESLI 2010). While some departments have made a step forward in having windows into laboratory spaces to show more technology and transparency in research and education, well-designed displays can go further to enhance understanding of the discipline that is relevant to today's society. Geology is a capstone science besieged by pressing issues: global climate change, economic resources, sustainability of Earth systems, and science policy. Earth science issues are important and germane now (e.g., NESTA 1987; AGI 2004; Kelly and Burks 2004; Bralower et al. 2008; Manduca et al. 2008), as indicated by the UNESCO declaration of the 2008 Year of the Planet Earth (UNESCO 2008). Geoscience departments worldwide need to actively utilize their campus buildings to tell the stories of global events and environments.

Earth science is commonly part of the required curricula in early grades but sometimes becomes only an optional science in high school (9th–12th grades) (Barstow et al. 2002; Lewis 2008). During high school, preparation for college generally focuses on chemistry, biology, physics, and mathematics – the "hard sciences." Thus, by the time many science-oriented students finish high school, Earth science is no longer on their radar, and they are off to the "hard science" majors. Earth science should be at the forefront (Bralower et al. 2008), as it integrates so many allied sciences such as biology, ecology, geography, mathematics, physics, chemistry, and computer science.

To inspire the next generations of students, Earth science departments would benefit in a physical environment that reflects an enthusiasm for Earth science. Too often geology is relegated to the dark, dirty, dusty basement of a campus building (Springer et al. 1997). Although many scientists are so focused they could literally work "in a cave" as long as it was a scientifically functional cave, we are aware that we can be positively affected by light and our environment (e.g., Knez and Kers 2000;

Newsham et al. 2009). Thus, a supportive learning setting that inspires enquiry may do much to advance Earth science. Our discipline needs to utilize geologic displays as both science and art to enhance our position of inspiring prospective majors.

2 Motivation and Rationale

2.1 Vision and Building Realities

It is often difficult to know what goes on in a campus building without reading the paper materials on the walls and doors. The goal is to have campus buildings literally "sing" about the academic discipline inside and its relevance. Clearly the concept of a positive experiential environment (Chan et al. 2011) as presented here is outside of the norm. Many long-held institutional traditions, attitudes, and budgets conspire to keep the buildings uniform. Breaking outside of the mold and personalizing buildings inside can set a department on new trajectory to strengthen its visibility and its programs in multifaceted ways.

2.2 A Proven Example

The award-winning Frederick A. Sutton building (called the Sutton building) for the Department of Geology and Geophysics at the University of Utah has proven to be a highly successful building that is used to show how geology and art can be effectively integrated in the designs and displays (Chan 2010) and why it is worth the extra investment. An academic building must still fulfill all the practical space and programmatic needs for teaching and research, but thinking carefully about the designs and displays can increase the impact of the space. What is unusual is that the Sutton building is a university academic department's home, a working teaching and research facility for students and faculty. Although it is not a museum, the public spaces have a museum feel.

The model of an inspiring, learning environment calls upon familiar concepts of creative cultures, storyboarding, and displayed thinking (e.g., Vance and Deacon 1977). Here we made a conscious decision to promote a personal or human connection into the academic environment. This award-winning structure is a LEED-certified building (Leadership in Energy and Environmental Design, sanctioned by the U.S. Building Green Council) that sets an example for sustainable practices.

Inside the building, many geologic concepts can be expressed in scientific and artistic themes, complemented by "earth tones" interior finish colors (Fig. 1). In our example, all the displays in the Sutton building are coordinated and aimed at teaching and inspiring students. All the major displays are placed in their particular place for certain reasons and/or to articulate geologic relationships. Polished rock slabs and

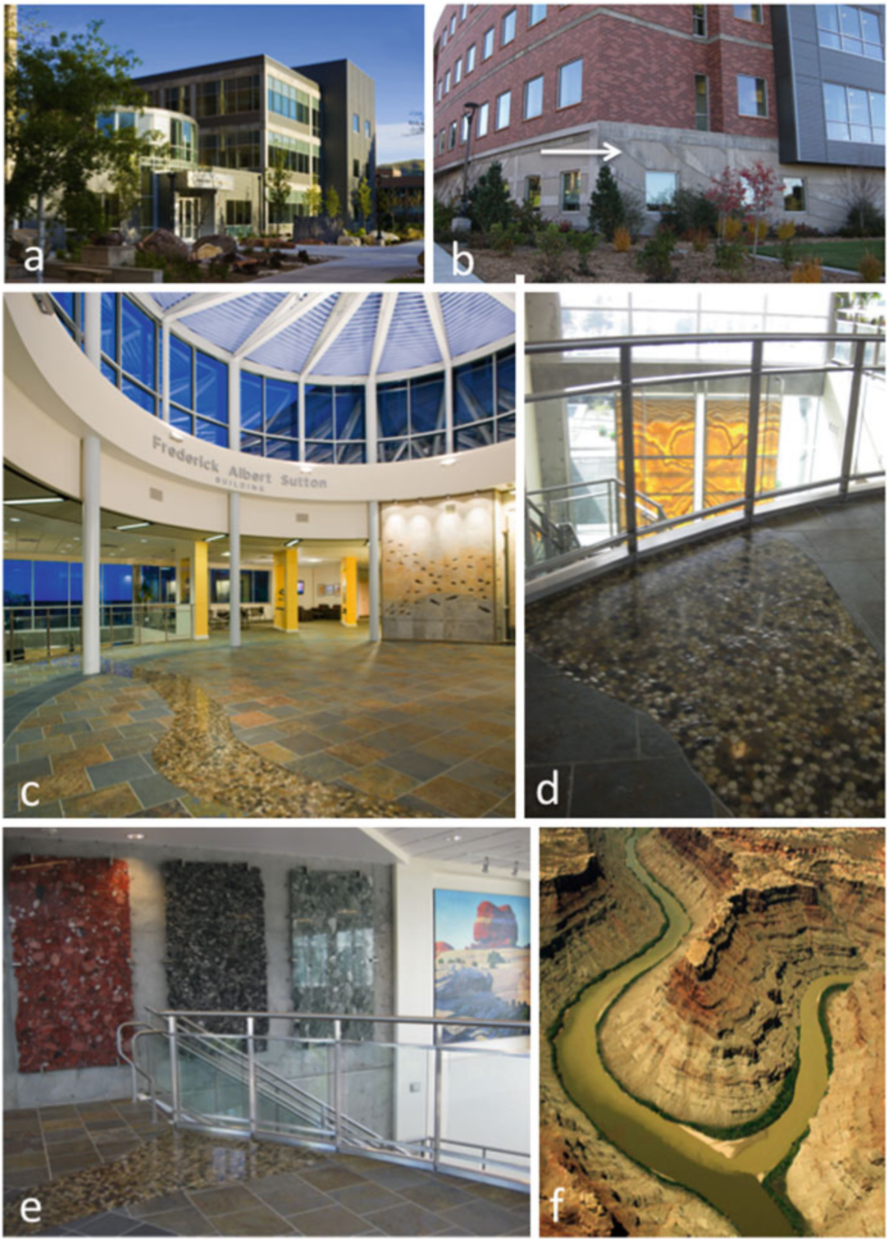

Fig. 1 The Sutton building (**a**) has a river theme that expresses how the landscape of Utah was formed by rivers. (**b**) A raised-relief, stylized, cross-bedding pattern (*arrow*) in the Sutton building's concrete foundation attests to the geologic process of sediment transport, consistent with the river theme. (**c**) Inside the building is a stylized river-pebble tile (encased in clear epoxy resembling "water") creating the sense of a real river. Pebble tile in the river path courses through the center of the building, connected to patterns of dry riverbeds in the xeriscape of the building's

fossils are common in the hallways, displayed with stainless steel brackets that give them an artful sense (Figs. 1, 2 and 3). Each specimen has an informative label giving geologic content and other information.

Overall, the four floors of the Sutton building are stratified with respect to subdisciplines. On the Sutton main entrance floor, there is a river theme because much of Utah has been carved by rivers. The exterior of the building is surrounded by xeriscape (a new departure from the traditional grass) that has a stylized dry riverbed of cobbles. The river theme conveys the idea that rivers flow from the mountains to the valleys (in this case from the east, Wasatch Front, to the west – Salt Lake Valley). The outside riverbed has branching tributary forms on the east side that converge to a river pattern inside the building of a sinuous pattern of river-pebble tile encased in clear epoxy (to simulate a wet-looking stream) (Fig. 1c, d) that "exits" and connects out the west side of the building to another dry riverbed in the xeriscape. Near the river-pebble tile, the rock slabs on the wall are three slabs of conglomerate, placed there because conglomerates are the kinds of deposits that rivers leave behind. Each of the three colors in the conglomerate slabs indicates different geologic conditions of oxidized iron (red), anoxic or oxygen poor (black), and reduced iron (green) (Fig. 1e).

The building's displays make an important bridge to the teaching and research that goes on within the department. Windows into the laboratory spaces allow visitors a view of the research being conducted. In some cases the displays are directly related to the research with explanatory signage, such as the display of early man skulls and skeletons that relate to the geochronology dating of the ash layers the bones are found in.

The main lobby of the Sutton building resembles a rotunda or atrium that lets in a lot of light, thanks to the new energy efficient technology for glass (Fig. 2). Although the names lobby, rotunda, or atrium couldn't be used because of various code regulations, we call the entry area a geologic name of "confluence" because it is where the old and new building came together. Correspondingly, the confluence reflects the river theme. A large aerial photograph of Utah's famous meeting of the Green and Colorado rivers hangs prominently (Fig. 1f), along with a history quote about the rivers from early explorer and geologist John Wesley Powell. The combination of these design elements incorporates a sense of history, and the excitement of exploration, along with teaching concepts of rivers.

Fig. 1 (continued) exterior (Photo by P. Richer). (**d**) The river tile pattern ends toward the edge of one floor and the pattern picks up in a "pool" on the lower floor beneath and continues to exit to the west (toward the physical Salt Lake Valley). (**e**) Polished conglomerate slabs placed by the stylized river show the types of deposits that rivers leave behind. The different colors *left to right* correspond to different chemical conditions of oxidized iron (*red*), anoxic or oxygen poor (*black*), and reduced iron (*green*). A colorful large $8 \times 8'$ original oil painting was commissioned from Utah artist John Collins to show an eroded Permian rock remnant. (**f**) The lobby area joins the old and new buildings together and is named the "confluence" – a geologic concept consistent with the river theme. Correspondingly, Utah's most famous confluence of the Green and Colorado Rivers is displayed in an aerial photograph by Michael Collier (north is to the *right*) (Color figure online)

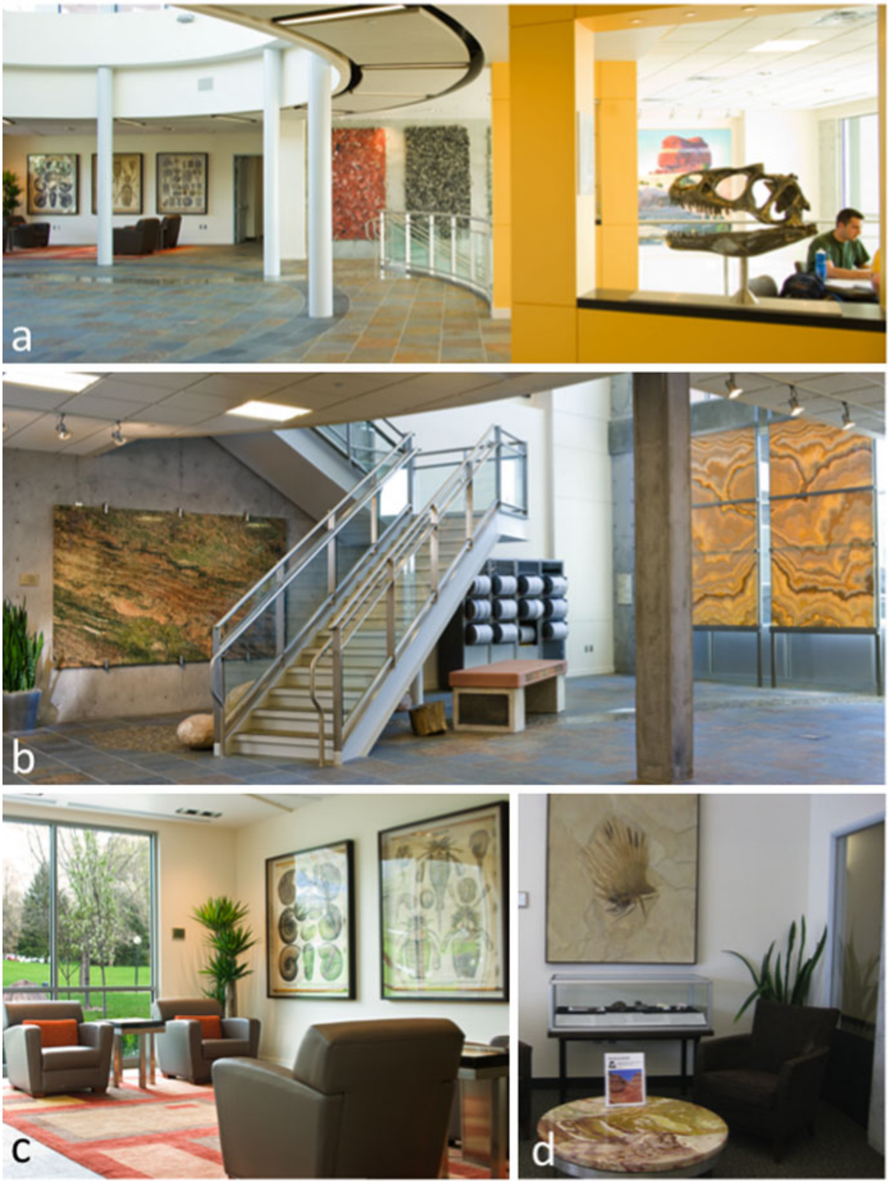

Fig. 2 Inside the Sutton building, a high concentration of displays (**a**–**d**) of geology as science and art present a museum-like feel that inspire visitors and encourage them to explore. Open, light-filled public areas are inviting spaces for students to gather at. Polished, translucent matched "bookend" travertine slabs filter the western afternoon sun (**b** at *far right*), making a dynamic display that changes with the time of day and light, while slightly masking the view of the outside building HVAC cooling tower (Photo credits (**a**) and (**b**): P. Richer)

Fig. 3 Each floor contains many polished rock slabs and fossils that serve multiple purposes as art, teaching artifacts, and signage. Floor signs show the number of fossils that equate to the floor: two fossils for the second floor (**a**) and three fossils for the third floor (**b**)

A major showpiece of the building in the round confluence is tiled wall with over a 100 Eocene fish (representing four different species) from the Green River Formation of southwestern Wyoming (Fig. 4). The fish are arranged to resemble a school of fish swimming toward the lecture hall. They "unconsciously" guide people where to go, as "artistic way finding." The small fish fossils are arranged like a school; the bigger fish toward the bottom of the wall are going in other directions, simulating a natural setting where bigger fish live deeper and swim independently. The field background of the tile wall shows a color variation from gray toward the bottom that matches the blue-gray slate tile floor. Gradationally the tile color lightens upward to give a sense of shoaling (Fig. 4). This overall display simulates

Fig. 4 A major floor-to-ceiling, curved stone fish wall in the main entry contains over 100 real fish fossils from the Eocene Green River Formation – arranged to resemble a school of fish swimming toward the lecture hall. The wall simulates shoaling of an ancient lake environment where the background field tile color of the wall grades from a gray at the bottom that matches the Brazilian slate flooring and gradually changes and lightens upward to a tan color. The two long center plaques list donor names etched on the same Green River stone so that the donor recognition is integrated into the central art piece

a sense of movement (swimming fish) in a lake setting, the environment the fish originally were a part of. The framing around the fish wall is laminated marlstone set on edge (perpendicular to bedding) to show cyclic oil-rich laminae, as well as some fish coprolites (Fig. 5a, b). Such materials are teaching tools for all student levels. The center of the fish wall lists the donors, integrated as an art piece. The entirety of the fish wall draws visitors to look and evokes a sense of wonder.

Around the corner from the fish wall is a separate plant wall of Eocene fossils (Fig. 5d). This display was literally "spawned" from the fish wall, as a friend of the department knew about plans for the fish wall and decided to donate his rare collection of plant fossils (from the same formation) that he felt would complement the fish wall. It was discovered that the plant fossil collection contained new species of fossils that had never even been described, so this was an important discovery for paleontology. The plant fossils went into a new display, arranged like leaves blowing in the wind, to continue and encourage the sense of movement and add to the wonderful diversity from the Eocene lake system.

In all the displays, proper lighting is a very important feature that should be considered early in the process, as it can be costly to make or add lighting modifications to finished walls and spaces. Many rock specimens were placed in a particular way to catch certain natural light and thus look different at different times of the day. This gives the sense that the displays are more dynamic instead of static, as they may change their look with the light (Fig. 2b).

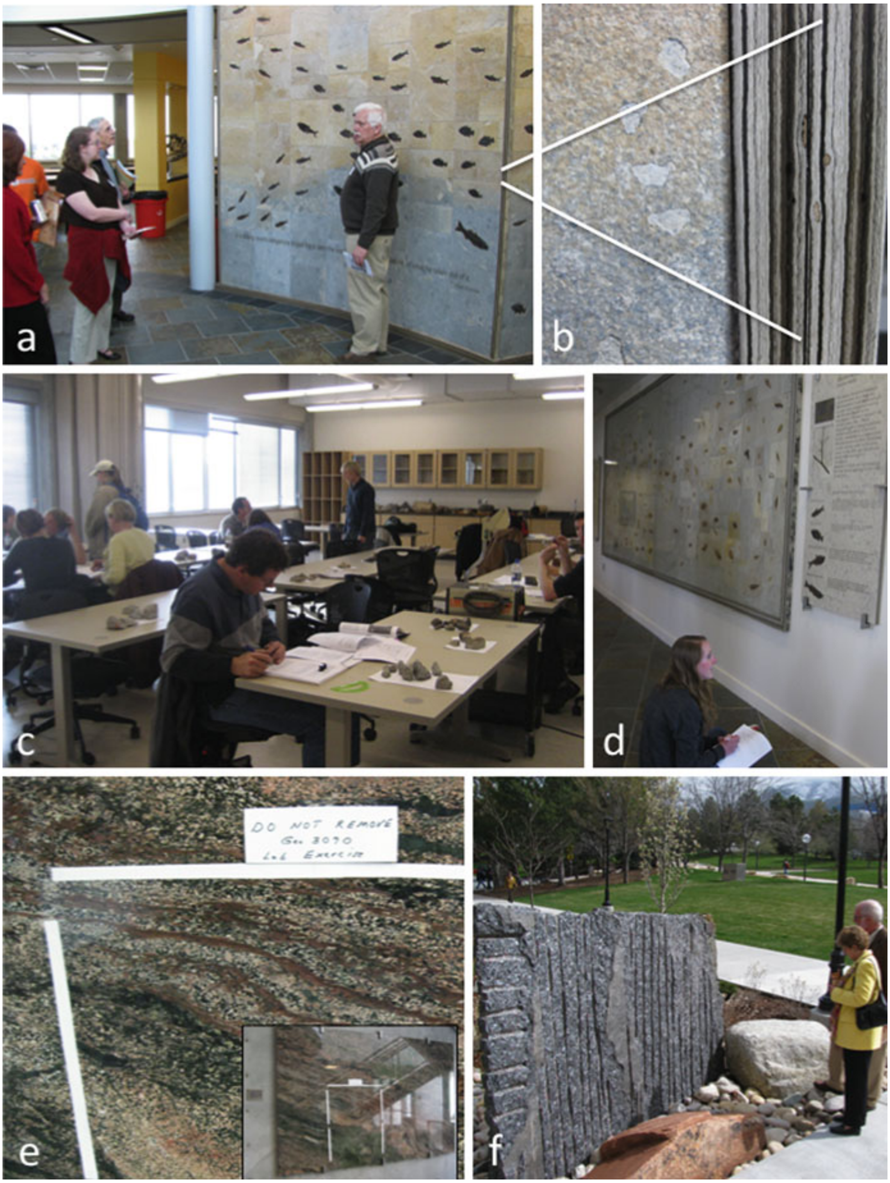

Fig. 5 All displays and design elements are used as teaching tools. (**a**) A professor tells the story of the four different species of fish fossils represented in the fish wall. (**b**) The edging of the fish walls is the same Eocene Green River stone turned on edge to show the natural lake laminations of the carbonate marlstone (keyed to **a**). The dark, organic-rich "oil shale" layers contrast with the lighter carbonate laminae. Some of the layers also contain likely fish coprolites (shown by rounded spots in the enlargement). (**c**) Teaching also occurs within light-filled traditional laboratory classrooms, as well as in the halls where students study the displays (**d**). Some faculty may even mask off particular portions of the display slabs (**e**, and context image at *lower right*) to get students to focus on documenting textural relationships. (**f**) Large rocks in the xeriscape help signal this is a geology building. A rough-cut "endpiece" slab of garnet staurolite schist is positioned so the morning light from the east makes the garnets glisten in the sun

Fig. 6 The displays of geology as science and art can be tactile and attractive to engage visitors. (**a**) Kids love touching the life-size Allosaurus skull cast (Allosaurus is Utah's state fossil). (**b**) A visiting school group places magnets on the slab of banded iron formation to determine which minerals are magnetic. (**c**) A visiting professional group utilizes the space for a small workshop/short course

2.3 Teaching Tools

In the majority of our classes, faculty use the displays often for mini-field trips to get outside the classroom and to engage students (Figs. 5 and 6). These show how geologic materials can be used to teach and engage students at all class levels from nonmajors and introductory levels to advanced levels (Table 1).

Table 1 Examples of exercises (not inclusive) utilizing the geologic displays for different level geology classes

Class level	Class	Example exercises
Introductory (nonmajors)	Geology National Parks	Identification of rock types
	Exploring Earth	Cross-cutting relationships
	Fossils and Life History	Examine/identify fossils
Majors (undergraduates)	Intro Earth Systems	Rock classifications, geologic processes from different rock types and textures
	Earth Materials	Specific mineralogy, textures, grain-scale petrogenesis
	Structural Geology	Products of deformation (e.g., brittle vs. ductile)
Advanced (upper-level undergraduates to graduate)	Stratigraphy/sedimentology	Clastic and carbonate classifications, textures, provenance, and depositional environments
	Metamorphic petrology	Pseudomorphic replacements and metasomatism
	Paleoecology	Fossils and environmental relationships, trace fossils, and taxonomy

Most faculty use different rock slabs for multiple examples and/or homework assignments. Touching a physical sample evokes a different connection than simple pictures in a class lecture.

Moreover, rapidly expanding smartphone applications such as the readable QR (quick response) matrix barcodes near displays can quickly deliver geologic information to students and visitors (Chan and Hatch 2011). The QR codes are connected to audio and video podcasts to increase the teaching capabilities and outreach potential of the geoscience displays or introduce students to sustainability concepts by explaining the "green" features in the building's design. The QR technology allows students and visitors to explore the displays at their own pace and enhance their educational experience with a sense of discovery.

2.4 Obstacles and Challenges

There are typically many obstacles that achieve something other than a "no frills," inexpensive "box structure." Getting a building constructed is a major task because it is piled on top of the already overworked faculty and administration. The first step is to find the right combination of people who will work well together on the project and share the previously outlined vision. An architectural group may believe they can showcase a discipline with colorful pictures, or they may be accustomed to creating a structure that is more of an architectural statement (instead of an academic statement). However, well-designed displays should be more tailored to the disciplines that will reside within the building.

Another obstacle is the usually limited funds to afford displays and to pay a designer who helps make sure they are properly proportioned and put in the appropriate places. Many state-funded buildings will designate 1 % of the building costs for art. In the case of the Sutton building, since it was privately funded (built without any state assistance), no funds were available for art. However, over $700,000 of in-kind donations was garnered for the building. Early in the process, being able to express a vision is important, because even without the initial funds to do something special, donors, companies, and even trades people working on the building caught the spirit of how this could be a special place. And many went out of their way to make it happen. Various companies and individuals were enthusiastic about contributing specimens and goods and anxious to have their products represented in a visible public building. This generosity contributed to its distinctive look. The use of art as teaching tools goes beyond what other buildings might typically have designated for art.

The norm for most campus buildings is to get a structure up quickly on a short schedule, thus cost effective. The architects and contractors of record work accordingly. Even in a privately funded building, the funds for the building must be run through the state (government) management because the building is at a state institution. In the case of the Sutton building, there was a conflict on who had the final say, the resident department (faculty representative), the University representative, or the state representative who manages the project for a fee proportional to the building cost and ultimately issues the contractor paychecks. This can be a major frustration when there may be differing opinions on needs – real or perceived.

The elements of an experiential environment have significant costs, approaching 1.5–2 % of the construction budget. Such elements are not accounted for in a traditional architectural program. For the Sutton building, it was necessary to convince the state Department of Facilities and Construction Management (DFCM) regarding the importance and value of the design elements. Through a process including active participation of the campus planning and design unit, there are now university budget stipulations that provide funding for the design elements of new campus constructions, and the experiential environment initiative is part of the selection process for consultants of new campus buildings (Chan et al. 2012).

Despite the challenges, it was possible to overcome many of these problems with open communication and early planning, a strong vision of the desired effects and outcomes, and dedicated parties who will work cooperatively to make it happen.

3 Outcomes and the Ripple Effect: A New Paradigm

This approach of an experiential, learning environment improves the process of planning campus buildings to a thought-provoking sustainable plan that involves and encourages departments to tell what they are about and to build a strong, vibrant unit. The Geology and Geophysics Department's goals were to consolidate into one building in order to foster faculty community, increase our visibility, extend outreach, increase majors, and strengthen programs. After the 3-year period of building programming, construction, and completion of the Sutton building, the results were a doubling in the number of undergraduate majors, new scholarship donations and the gift of an endowed professorship, 2,000 documented off-campus visitors within the first year of opening, and a revitalized department that now is literally bursting at the seams. Faculty and students of the department are proud to be in the building. It is common for students from across campus to hang out in the Sutton building, even if their major is music, physics, or social sciences. Some people say they just like to walk through the Sutton building on their way to another building. A coffee shop near the lobby entrance makes it an inviting area.

The experiential environment was the springboard to achieving and supporting the academic plans of growing programs and increasing visibility. The outcomes of this synergistic approach broadly affect programs, operations, community, student experience, sustainability, technology transfer, and campus planning across multiple areas of integration. It may also involve donors and alumni while setting faculty and individual departments on a rejuvenating path. Trade people working on the building were excited and proud to show their families their work. Some donations were a direct result of people hearing or reading about the building and imagining how their rock, mineral, or fossil specimens could be displayed. Many campus and off-campus groups (Fig. 6) request use of the building for small board meetings, department retreats, graduation receptions, fund-raising events, professional workshops, press conferences, and even a memorial service for an alumnus.

Recently, the Governor of Utah chose the Sutton building to hold a press conference unveiling his 10-year energy plan. The unique displays of the building make it much more of a multiuse structure that has become a "campus attraction." Various faculty committees and university project design teams that have toured the Sutton building as a model in guiding new construction projects on our campus. Building teams from neighboring campuses and some teams from out of state have also visited.

The outcome and response has been so positive for the Sutton building (Table 2) that the plans and process for achieving these results are now codified into guidelines to foster the same success for other construction projects on the University of Utah campus. Other campus units are now excited to catch a vision of how to enhance their own resources. This can be one of the most positive and dramatic changes to campus planning and designs nationwide in decades. These synergistic design innovations may revitalize campuses to encourage stewardship of new and future societal resources, discoveries, and inventions. Many initiatives are a direct or indirect result of the initial Sutton building that captured the essence of the experiential learning environment on the University of Utah campus.

4 Discussion

The use of geology as science and art can help build a strong department with heightened visibility in a building that invites exploration. Even faculty who were initially indifferent to physical displays or designs can see the difference the building

Table 2 Sutton visitor comments

From friends and alumni (*some combined*):
"a smashing success and the new building is brilliant," "nothing short of spectacular," "totally inspiring"
"stunning and will also serve as a recruiting tool for faculty and students"
"congratulations … the displays combine science with art which is rarely done effectively"
"the most spectacular and interesting geology building I have been in"
"absolutely wonderful," "outstanding," "fantastic," "absolutely terrific," "exceptionally impressive"
"building is beautiful!!! I was speechless …. I had dreams of being a student again. WOW!!!"
"It's the concept and the way people feel when they're in it – absolutely loved it!"
"I loved the new building! I keep recommending it as a destination for geologists and non-geologists alike"
From a professional designer (not associated with the project):
"I marvel at the designs…. The choice of materials, colors and furnishings create an exciting effect of total balance and motion. The displays on each floor relate to the department, and add to the absolute success."
From partners:
"Thank you for including us on your innovative project", "Glad we were able to participate"
"Again, great job on the building. I knew our wall would be great, but I really enjoyed the design of the building as well as the other displays and specimens."
From peers:
"The building is spectacular; I could hardly believe it's for geologists!"
"I am envious of your new building …. That fish fossil wall is arguably the best geologic art I have or probably ever will see in my life. I will definitely encourage students to apply to your program."
"Congratulations on your breathtaking new facility. I can't even begin to imagine the work involved in putting that together."
"When I visit the Sutton building, it's the same feeling of awe when you go into a museum or a church. It's almost spiritual!"
"My daughter and I had a chance to tour your beautiful building – WOW. She had read about it and wanted to see it, and it lived up to its billing."
From a recruiter: "I can't think of any other educational structure that blends science and art, in the way yours does, to create a building that is equal to the wonderment of the content being taught there. I was truly inspired…."

Many actual comments from visitors that have explored the building show that this is not the typical admiration for an architectural structure, but is instead about how they *feel* and experience the building

makes on colleagues, students, and visitors. The positive outcomes and ripple effect in this completed example exceeded expectations such that is has now become a model for other units across the campus and even globally (Chan et al. 2011).

The Department has an alliance with a university in Germany. As German geology students have visited the Sutton building through an exchange field trip, they were intrigued, amazed, and in awe of the displays. This confirms the concept that good, artfully displayed science can transcend cultures, because art, like music, can be a universal language.

Not all departments are well endowed with funds to make a huge impact, but even expressing or initiating the vision (e.g., in a newsletter or by personal contacts) may be able to help pique the interest of potential donors or alumni and friends. A department may let its constituents know they are after a new look to showcase the department's assets and have visual artifacts to teach, inspire, and engage students. Alumni or friends may step up, as they see an opportunity for mutual benefit, and can feel great satisfaction in having their treasures find a good home where they can be shared with a broader community. As an example, a newspaper article about the Sutton building's displays spurred one family to call and express their interest in donating a fine petrified wood collection for display. This particular collection was special because the family had retained the documentation of the exact age, formation, and locality of the specimens. The documentation means that the petrified wood can actually be used in research to see what kinds of trees dinosaurs might have eaten, or climate changes reflected in tree rings, or how borings are preserved in the outer bark. Thus, the approach of geology as science and art can occur on many levels, starting off with even a few well-placed, striking wall displays from a department's collections and resources. Changes in small increments can lead to bigger increments with more widespread enthusiasm as people respond to the artistic aspects of displays.

An environment of creative displays and designs will foster interdisciplinary collaborations, where other sciences can see themselves interfacing with Earth science. Our discipline must capitalize on the visual resources and materials of Earth science that show the relevance to global issues and research. The engagement of each student in their educational environment becomes part of their academic heritage. The ultimate objective is that when a student walks into a campus building such as the Sutton building, something inside them says, "Wow, I want to be a geologist (Chan et al. 2011)." This moment of inspiration is what a university desires for each of its students; this is a step that will enlarge the future of Earth science.

Overview

Status Quo and/or Trends

- It is common for campus buildings to be cost-efficient box structures, and geology departments are often relegated to dusty spaces and basements.
- Faculty are typically too busy to "make a fuss" over department designs and displays, although studies and this case example show that visitors enjoy visual artifacts and museum-like displays, and there can be a huge impact on the department's outreach and teaching capabilities.
- Campuses and academic buildings need to be more engaging to capture and hold the interest of today's students. A changing focus from traditional architecture to an integrated architecture of design elements can capitalize on visual materials to inspire the next generations of earth scientists.

(continued)

(continued)

Challenges to Overcome

– Budgets conspire to keep displays minimal, but partnerships with companies and in-kind donations can provide a valuable start.
– It can be a daunting and demanding task to take on extra work of displays to showcase the academic discipline, but a clear vision and willing parties who will openly communicate can make it work.
– Good early planning can go a long way to reaching goals that will have beneficial outcomes.

Recommendations for Good Practices

– Well-designed, geologic displays can help a department codify their educational mission and have an internal rejuvenating effect on a vision for the future. The museum-like feel creates a unifying sense of community. The positive work environment will strengthen productivity and build interdisciplinary bridges.
– Even a modest start on displays can grow to bigger plans over time, often with unexpected but pleasant ripple effects. Earth science artifacts raise visibility about the discipline and offer the opportunity to increase partnerships and donations from within the community.
– Intriguing and innovative displays presenting geology as both science and art have a profound power to teach, inspire, and engage students and visitors. Its potential outreach and outcomes leave a legacy that extends beyond traditional walls.

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Teaching Geoscience Research to Adult Undergraduates and Distance Learners

Hilary Downes

1 Introduction

As shown by the quality of the geoscience dissertations submitted by the finalists in the annual "SET awards for best student", traditional (18–22-year-old, face-to-face) undergraduates at universities in the United Kingdom and Europe are able to produce dissertation work of publishable quality. Does this engagement with research also extend to adult undergraduates and to distance learners in the geoscience field?

2 Who Are Adult Learners?

Adult undergraduates in the geosciences tend to belong to three different groups: (1) people who are new to higher education, having left school and sought employment before deciding to undertake a bachelors degree; (2) those who already have a bachelors degree and are in employment, but who wish to change the nature of their job and will be seeking employment in a geoscience field; and (3) retired people who are fulfilling a lifelong ambition to take a serious interest in the geosciences, perhaps because of a deep interest in some particular aspect. Thus, it is clear that this particular group of students displays a strong diversity of background and a wide range of experience. They therefore show a range of responses when exposed to the possibility of undertaking research within their undergraduate degree programmes. Some adult students have special requirements, such as needing to fill significant gaps in their background in mathematics or chemistry, without which they cannot understand the nature of many of the problems in geosciences. Others

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bring with them particular skills that are the result of their career choices and/or previous higher educational experiences, possibly even including a history of undertaking research in another field. As a result of this extreme range in knowledge and skills, adult learners show very different responses to undertaking research as part of their undergraduate curriculum.

3 Who Are Distance Learners?

Distance learners are a specific group of students (usually, but not exclusively, adult learners) who do not attend face-to-face classes on a university campus but who receive their education by remote means. Generally this entails receiving detailed course notes, supplemented by teaching videos (e.g. recordings of lectures and seminars). Such students communicate with their lecturers via electronic means (e-mail messages, telephone calls, Skype). They may also be part of a social network with other distance learners and/or with face-to-face students. Distance learners who are able to attend geoscience field classes can become part of the larger student cohort by making personal friendships with other students in their group, thus decreasing the feeling of isolation that is often part of the distance learning experience. The closeness of contact with other members of the group can also be enhanced by use of social networking sites.

4 Introducing Research to Adult Undergraduates

Introductory modules provide the basic concepts in geosciences and would not be an obvious place in which to introduce research ideas to undergraduates. However, while still providing the fundamentals of different parts of the science, it is possible to explain where areas of uncertainty exist. For example, within the sub-disciplines of geophysics and geochemistry, there are some major unanswered questions relating to the deeper parts of the Earth. Thus, the uncertainty surrounding the nature of the light element in the Earth's iron-nickel core (opinion among geoscientists is that it could be sulphur, oxygen, carbon or silicon or a combination of these light elements) or the nature of the chemical reactions that may occur at the boundary between the iron-rich core and the silicon-rich mantle can be introduced during a very early (year 1) class dealing with the internal structure of the Earth. It can easily be made clear in this context that we do not yet have a consensus among research geoscientists about the answer to these questions.

Adult geoscience students react to the information that "we do not know all the answers yet" in many different ways. For some, it is exciting to realise that they are entering a subject area in which there are still areas of fundamental uncertainty. Others find it difficult to understand that such critical problems have not yet been solved. Naturally a few students will simply want to know "so what answer do we give in the exam?" In this aspect, adult students differ little from traditional young undergraduates. However, some adult learners may have a background in chemistry, physics, engineering or mathematics, which enables them to raise questions or make suggestions regarding such problems. This may be the first occasion when they realise that they may be well placed to make a contribution to geoscience research, once they have mastered the basic principles of the discipline. Distance learners are naturally at a disadvantage in all of their classes in that, unlike face-to-face students, they cannot directly interrupt and interrogate the lecturer at the time that the lecture is being given but usually see a recording of it at a later time. On the other hand, a recording of a lecture can be rerun several times by a distance learner to catch information that may have been missed by face-to-face students, and they may take more time to reflect on that information and see links (or gaps) that the lecturer has not highlighted.

Advanced undergraduate modules provide the obvious link between the fundamental concepts learned in the early years of a degree with the methods and techniques that are applied in research. Although many pieces of assessed course work (e.g. posters, presentations, review articles and mini-projects) cannot be at the cutting edge of research, nevertheless they provide undergraduates with an opportunity to apply their knowledge to problems that resemble research situations (e.g. determining the origin and evolution of a suite of igneous rocks, unravelling the palaeoecology of a group of fossils). Students undertake a piece of assessed work that mimics the research situation but is of much more limited scope and has a guaranteed outcome (i.e. the lecturer has set up the project with the expectation of a specific answer). Such mini-projects give students a "taste of research" which can fire their enthusiasm for undertaking further research-like activity. Giving students an opportunity to make "recommendations for further work" at the end of their reports on mini-projects can produce responses that indicate genuine engagement with the problem being investigated. Distance learners can also engage in such mini-projects, as long as the material that is investigated is made available to them in some way that takes into account their special requirements (e.g. packaged material posted to their home, high-quality photomicrographs of rock samples, spreadsheets of data sent by e-mail and access to web-based databases).

Field classes present an excellent opportunity for teaching geoscience research. In some ways, every piece of individual field work undertaken by an undergraduate student (e.g. preparation of a geological map or a logged stratigraphic section) involves some aspect of research (the student has not seen this set of rocks before and therefore does not know what the finished product will look like until it is completed). Usually the area being investigated will be well known to the lecturer, but there are always opportunities for a student to discover some new aspect that may cause the lecturer to rethink parts of his/her anticipated "answer" to the assignment. The concept of multiple hypotheses can also be taught in field areas with complex field relationships. Adult undergraduates responses to being told "we don't yet know how these particular rocks were formed" are highly variable, ranging from

"Oh I'd love to work on that problem!" to "Well, if you [the lecturers] don't know, how do you expect us [the students] to work it out?"

Final-year undergraduate geoscience dissertations are examples of research-like activity, approaching real-world research situations. Classic geological field mapping, planetary remote sensing and petrological investigations of suites of previously unanalysed samples, all of these types of project give a student some sense of "going where no one has gone before". Adult undergraduates often achieve better marks in such dissertation work than in formal examinations, possibly because the more mature human brain often sees linkages and patterns better than younger human brains (see the extensive discussion and bibliography by Strauch (2010) who reviews research that has shown that changes take place in the brain that allow mature humans to see a fuller picture of the world and enhances their ability to make accurate judgments). On the other hand, such a piece of independent work is usually the most challenging part of an undergraduate geoscience degree, and many adult learners who have done well in taught modules often find it very difficult to undertake independent work. They can achieve high marks in written examinations, but fail to understand how to deal with the more open-ended situation of undertaking individual research. For distance learners, being isolated from their dissertation supervisors can be the biggest problem. They cannot just "drop in" to see their supervisor and bounce some ideas around. For them the simple act of showing a draft of a geological map or the draft of an entire thesis to their supervisor by electronic means can be challenging, in terms of file size or printing requirements. Nevertheless, some distance learning students report relishing the feeling of being the only person who has ever worked on this particular set of data or suite of samples.

5 Can Adult Undergraduates and Distance Learners Undertake Real Geoscience Research Projects?

If a final-year undergraduate dissertation by an adult undergraduate or distance learner is genuinely a piece of novel work, then the submitted thesis constitutes real scientific research, and the results of which should be made available to the wider world. An external examiner of the B.Sc. dissertation may suggest that it is "suitable for publication", giving the student and supervisor an external positive review of the work. Such a signal from an unbiased authority is often the first indication to an adult undergraduate that their work is of particularly high quality and would have significance to the wider scientific community. Adult undergraduates who achieve this level of competence in their first piece of independent scientific work are undoubtedly exceptional students. It is particularly pleasing when an adult student with little or no previous scientific experience manages to achieve this level of competence during their undergraduate studies. These students may have had to make a special effort to improve their understanding of techniques such as GIS, data processing and statistics in order to reach this competency.

Preparing the content of a B.Sc. dissertation for publication in the scientific literature inevitably involves further work on the part of both the student and supervisor. Most geoscience researchers publish their first paper while undertaking doctoral studies, so it is unusual for a new graduate to be in this position. The supervisor presumably has a publication record, so she/he should be able to guide the student through the process. Adult undergraduates, particularly those who have already had careers in a scientific field, may feel that they are able to turn their thesis into a paper by themselves, but publishing conventions vary greatly between scientific fields, and the background they have may not be particularly appropriate to geoscience publications. Distance learners are at a particular disadvantage of not being able to discuss their work face to face with their supervisor, but modern electronic media have greatly helped to increase communication so that drafts of manuscripts can readily be sent back and forth between supervisor and student. Examples of articles published by adult students and their supervisors, based on B.Sc. dissertations, include those by Podolsky and Roberts (2008) on faulting in Hawaii and Spence and Downes (2011) on compositions of prehistoric lava flows from Mount Etna.

6 Conclusions

It is clear that competent adult undergraduate students can undertake genuine research projects which are ultimately publishable in the geoscience literature. Such students are exceptional, particularly as in many cases they have no scientific background beyond what they have learned in their undergraduate degree. Others may have a background in a different scientific discipline. Distance learning is not a barrier to such an achievement but presents its own particular problems with respect to communication between student and supervisor.

Overview

Status Quo and/or Trends

– Adult geoscience undergraduates have widely differing backgrounds in terms of their basic scientific knowledge and experience.
– Some adult undergraduates can achieve high levels of competence in geosciences and can undertake genuine scientific research within their final-year dissertations.
– Distance learners have specific issues relating to not being able to interact with their peer group and their lecturers in "real time" but nevertheless can also undertake geoscience research of publishable quality.

Challenges to Overcome

– It can be hard to match a particular student with a dissertation topic that is a genuine piece of research (i.e. the supervisor does not already know the

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"answer") but which sparks the interest of the student and can also be achieved in the limited time available for adult students.

– Adult students react very differently to the idea that they are now at the forefront of their subject – some find this concept very stimulating, whereas others cannot cope with the uncertainty of not knowing the final outcome of the research.
– Distance learners often need more focused support than face-to-face students, particularly in terms of communication with their supervisors.

Recommendations for Good Practice

– Introduce the concept that "we do not know all the answers" very early in the study of the geosciences.
– Appreciate that adult learners have a wide range of backgrounds and are most emphatically not as homogeneous a group as typical young undergraduates.
– Emphasise the areas of geoscience in which adult undergraduates have made contributions to research (e.g. using the resulting paper in undergraduate classes, putting copies on departmental notice boards).

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Geoscience Internships in the Oil and Gas Industry: A Winning Proposition for Both Students and Employers

Rolf V. Ackermann and Lucy MacGregor

1 Introduction

Many geoscience students enter graduate school out of enthusiasm for the subject, but without a clear idea of their future career options. This is especially true for those students who are not attending one of the traditional "oil schools" that has tight ties to geoscience and engineering functions in oil and gas companies. Students at schools with tight industry ties do not all pursue internships, and many students at other schools do: There is a large degree of variability that changes as faculty, students, and companies evolve. This chapter is intended to provide a broad view of internships, regardless of the type of school, to a variety of faculty – especially those generally unfamiliar with internships.

Proactive students can generally obtain an internship if they so desire. By pursuing an internship the student not only demonstrates active engagement with their career but will also gain valuable technical and corporate-culture experience – including an understanding how applied research is conducted in a commercial setting. Students often get to apply what they are studying or learn something new within their specialty (e.g., applying sequence stratigraphic concepts to building a 3D geocellular model based on well, seismic, and engineering data). At the end of 3 months, the student should have a clear idea of what the oil and gas industry has to offer and therefore be well prepared to move forward in terms of career choices and/or leverage the experience in forming a research program in an academic setting that links to industry.

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2 Opportunities

2.1 A Time for Growth

By electing to pursue an internship, the student and their faculty advisor have elected to augment and enhance the student's postgraduate education. This will take the form of new technical and scientific skills that are easily identified and often not possible to acquire at the university. However, there are other skills that are less easily quantified but make the student a stronger professional: interaction with a range of other technologists, the experience of being managed in a corporate environment, balancing science and business needs (e.g., what is the definition of "done"?), and project and time management. All of these skills translate to later employment in both industry and academe.

2.2 Landing an Internship

Most intermediate- to large-sized oil companies have internship programs that generally last 3 months. While most of the companies have universities and departments where they routinely recruit for interns, their internet sites usually have a facility for any graduate student to use for applying for an internship. The proactive student will ensure that their resume is straightforward and engaging, using keywords well describing their experience, research, and ambitions. Flexibility in internship dates will also help the successful candidate.

2.3 The Project

Where there are extant ties between faculty and industry, a student stands a good chance of obtaining an internship that is directly applicable to their own research – whether it is through the exploration of the topic in an applied setting or acquisition of relevant skills, such as seismic interpretation. Alignment of topics is not a prerequisite for success, however. Projects in different subdisciplines or another geoscience discipline provide an opportunity for an incredible amount of learning and growth in a short amount of time. Regardless of topic, during their internships students should be watching for opportunities to leverage their thesis or internship skills in order to strengthen their graduate school or internship project. Feedback from a number of interns from different companies is that it is not the specific project they worked on, but rather the environment and industry mentor that facilitated their learning.

2.4 After the Internship

Student internships are a major recruiting vehicle for both oil companies (from oil majors such as ExxonMobil and Total to smaller independent companies) and service companies (e.g., Schlumberger or RSI). From the company's perspective, they have seen how the student deals with the company's culture, systems (e.g., the computer help desk), and how they handle corporate bureaucracy. They have also seen the student's strengths and weaknesses (technical, organizational, stress management, professionalism, etc.).

At the end of 3 months, both student and company know each other well and are positioned to move forward in terms of career choices and hiring, respectively. The student should be able to determine whether a career in industry or academe is more attractive based on their own goals and experience. A large number of interns elect to pursue permanent employment within the oil industry.

Regardless of whether the student is employed by the company, he or she now knows several people within the industry. Their former mentor can speak with some authority regarding the student's skills, ability to focus and adapt, and employability. And of course, the student now has a significant new element for their resume. Any company considering the student for permanent hire will know that the student has at least some idea of how it is to work in a company. Finally, if the student elects an academic path, they have some understanding of industry and how to tailor grant proposals and funding requests so that they are relevant to industry problems. This is a key advantage when applying for funding to many organizations, both commercial and governmental, where the applicability of the proposed research to industry problems must be demonstrated.

3 Experiencing Applied Geoscience

The vast majority of internships in the oil and gas sector are in what are called operating units, as opposed to in research groups. Operating groups are in general cross disciplinary and are responsible for meeting specific commercial goals within a field or region. An internship deployment in an operating unit may be geographic (e.g., looking at regional trends in a sector of the Gulf of Mexico) or lifecycle and field specific (e.g., development of Mad Dog Field in the Gulf of Mexico). These projects offer the greatest potential for learning new skills that will be applicable in an industry-focused career. For example, the student may learn how to interpret seismic data, how to prepare seismic for and then run an inversion for reservoir properties, or how to build and populate a 3D geocellular model using geostatistics. The student's contribution to the technical body of work is both important and, when of high quality, lasting. The most valuable thing to be learned, however, is how to balance scientific rigor with business-driven deadlines.

All research conducted in the oil and gas industry is applied, with metrics in place to define success or failure, as well as test implementations for verification. Some large companies conduct very forward-looking research ("Blue Skies Research" or "Blue Sky Science") that may not be immediately applicable or implemented for many years or even decades. However, even projects like this must have a demonstrable potential payoff at some point, which can take the form of improved seismic acquisition and processing, more efficient and effective reservoir depletion, or new exploration and production infrastructure that is safer and more cost-effective.

Student internships within research groups may be on short-, mid-, or long-range research projects. The student will work on a specific task that fits within and contributes to a larger framework. Their work will be very specific and lasting, and research in the sense that it is a component of something larger that is defined and championed by the mentor, who will see it through to its ultimate completion. A takeaway for the student is that applied research consists of a series of small projects that are regularly reviewed so that efforts can be redirected or halted if necessary. Another takeaway is that there must be metrics that can be used to quantify success or failure in place before a project commences. The student will also gain an appreciation for where their work fits into the bigger picture. This contextual understanding of research and applied geoscience in a business environment both broadens them as a professional scientist and strengthens them as an employee in both industry and academic settings.

4 Industry-University Research Ties

Within industry, research is viewed as a key differentiator providing commercial advantage over competitor companies. Such advantages can take the form of more effective field depletion, safer operations, or more cost-effective production programs. Additionally, research programs are often showcased to potential partner National Oil Companies and foreign governments in order to demonstrate that the company is the partner of choice.

Where oil and gas company has a research division or group, internships are a very important component of the technical program. They are not only a vehicle by which to accelerate technology development but also a means by which to forge ties with discipline-leading academics and their students. These ties benefit all involved and provide corporate research staff with different ideas that could accelerate their own program and provide faculty with industry perspectives that are potentially very different from their own.

These ties can be fostered by researchers on both fronts. For example, industry geoscientists overwhelmingly attend the American Association of Petroleum Geologists (AAPG) and Society of Exploration Geophysicists (SEG) meetings – faculty can learn a great deal by attending the technical program of such meetings. Corporate researchers benefit from visits to allied faculty at universities by meeting students and researchers and attending colloquia. Involvement with committees of professional societies is beneficial to all.

In order to truly forge close ties through continuous engagement between the company, a student, and his or her advisor, it would be beneficial if more Ph.D. projects were designed around continuous interaction with the company. In such well-designed projects, the company could provide data for the student to incorporate into their analysis. The student would return to the company for 2–4 internships, with some aligned with their thesis and some related in such a way that the student learns news skills.

An infrequently pursued activity to strengthen ties is for faculty to spend all or part of their sabbatical embedded at an oil and gas company. For such an "internship" to happen, there already needs to be a champion at the company. However, over the course of 6, 9, or 12 months, the faculty member will forge ties with the many technologists involved on the project, from geologists to engineers to business analysts. The faculty member brings a fresh perspective to the problem at hand within a framework that they are also learning from.

5 Elements for Success

There are several elements that lead to a successful internship for both the company and the student involved. Success is defined here as an experience where the student has learned something valuable, goes home with an appreciation for applied science/research, and has some new professional contacts. For the company, success is defined by a solid piece of technical work that can be used and/or built upon versus being placed on a shelf.

5.1 Responsibilities of the Company

- Select technical staff who will be a mentor using two criteria:

    1. Ensure that the mentor *wants* to mentor an intern. Junior staff will often see interns as a burden, especially when they are still trying to establish their own careers. Mid-career to senior staff are likely to be more successful mentors in that they have watched junior staff both fail and succeed at new things, and they want to give back to the profession.
    2. Ensure that the mentor is given both time and acknowledgment by management for their efforts. In other words, time lines for their own technical deliverables may need to be extended by a few weeks in order to factor in time devoted to mentoring. In addition, there must be acknowledgment that mentoring is a valuable and important component of the company's technical and recruiting programs.

- Plan a 3-month internship by acknowledging that really only 2 months is usable time: A full month is lost to start-up time, getting software working, logistics, corporate intern events, documentation, and presentations.
- Provide a well-defined project that can be *completed* in eight calendar weeks, including a reporting schedule for the project plan, midpoint progress report, and final presentation. It is important that there be a formal, final report and presentation, and the student *must* be held to this requirement.
- When defining the project, assemble something that provides a good technical experience and learning opportunity for the intern, regardless of who it is.
- Align the *intern to the project* available while providing growth opportunities through exposure to areas that are quite different from those they are pursuing in their academic studies.
- Permit and encourage the student to present the results outside the company to their department, a professional conference, or as a journal article when possible.

5.2 Responsibilities of the Faculty Advisor

- Design student projects, especially PhD projects, around working closely and continuously with an industry partner.
- Recognize that students mature at different rates. For example, not all PhD students are ready for an internship during their first summer. Also, recognize that students who are not self-starters will need much more structure during an internship.
- Encourage students to do internships at the right time for them.
- Proactively use their professional network – including other faculty in their subdiscipline – to find out about companies that will be having internships the following summer. Note that most internships are awarded during the recruiting season of September–November for the following summer.
- Encourage students who have completed internships to share their experience, project goals, methods, and results with the department, whether that be at a Lunch n' Learn or as part of a colloquium series. This hinges on the approval of the host company to do so – the project may have been confidential and/or proprietary, and the student and advisor need to be sensitive to this. Requesting such permission early in the internship provides enough time to secure the required permissions. There could even be the opportunity to present the results at a professional conference or as a journal article.

5.3 Responsibilities of the Student

- Choose an internship project aligned with their goals (both technical and career goals) and interests. This choice may not be immediately obvious and require some thought. At times it is not possible to know what exactly what the project will entail when the opportunity is with an operating unit: The topic may only be defined loosely, e.g., *refine the sequence stratigraphic interpretation of a reservoir interval.*

- Maximize opportunities to learn from industry professionals across a range of disciplines during the internship. Interns should ask questions and engage with the business. Simple strategies such as listening to discussion of problems can often provide new perspectives on how issues are addressed.
- During the internship the student is treated as a company employee. It is an obvious but important point that they should therefore behave as such, making sure that their presentation and behavior is appropriate to the environment they are in.
- The student needs to take the requirement of a good final presentation and report that documents what was done and how very seriously. Documentation in an industry setting is critical regardless of whether the results are a success or failure. This is because it becomes a permanent record in the body of work, and in the future staff not involved with the project at the time need to know and understand previous efforts.

Overview

Status Quo and/or Trends

– Internships in the oil industry provide students with invaluable technical and corporate experience that will serve them well, regardless of their career path.
– Internship experiences form a foundation for choosing a career path and technical directions.
– Oil companies use internships as way to accomplish discrete technical goals, as well as a major recruiting vehicle.
– Both companies and faculty can use internships as a means by which to forge stronger research and professional ties.

Challenges to Overcome

– The mentor at the oil company needs to be the right person, who wants to be a mentor, is not a junior staff member, and is appropriately recognized for the time and effort it takes to design a successful project and be an effective mentor.
– Faculty advisors do not necessarily appreciate that they play important roles in the student's successful internship. The faculty advisor needs to advise the student as to whether it is the right time in their career to do an internship.

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Recommendations for Good Practices

- The project needs to be well defined and achievable in a relatively short amount of time.
- The mentor needs to be the right person.
- The student needs to be ready for an internship both technically and professionally to embark on this important effort and take it very seriously.
- The faculty advisor needs to support the student in sharing and applying what they have learned.

Part IV
Pedagogical Examples: Use of Technology

Integration of Inquiry Fossil Research Approaches and Students' Local Environments Within Online Geoscience Classrooms

Renee M. Clary and James H. Wandersee

1 Introduction

Our current research investigation extends inquiry-based fossil research in local field environments for online students. Using Johnson and Troll's *Cruisin' the Fossil Freeway* (Fig. 1) as an inspiration and a loose guide, we merged field-collecting opportunities with investigation of informally displayed fossils. Our Fossil Freeway project probed whether online students can successfully research fossils from their local areas and utilize them in the reconstruction of two paleoenvironments from their geologic past.

Although the general concept of sense of place has been familiar in geography education and environmental education since the 1990s (Matthews 1992; Nabhan and Trimble 1994; Schneider 2000; Spirn 1998), we developed and researched a *Botanical Sense of Place*© (Wandersee et al. 2006) and a *Geological Sense of Place*© (Clary and Wandersee 2006) to improve students' botanical and geological understanding. We defined "Geological Sense of Place" as an affective and intellectual state that can be determined through our writing templates, which retrieve students' memories of Earth that are linked to particular places and events that made an impression on the students during their youth (Clary and Wandersee 2006). Sense of place research has also correlated geological interpretations with cultural identifications and sustainability (Semken 2005; Semken and Brandt 2010).

We implemented the Geological Sense of Place© (GSP) writing template in college classrooms, and analysis revealed that for the vast majority of college students,

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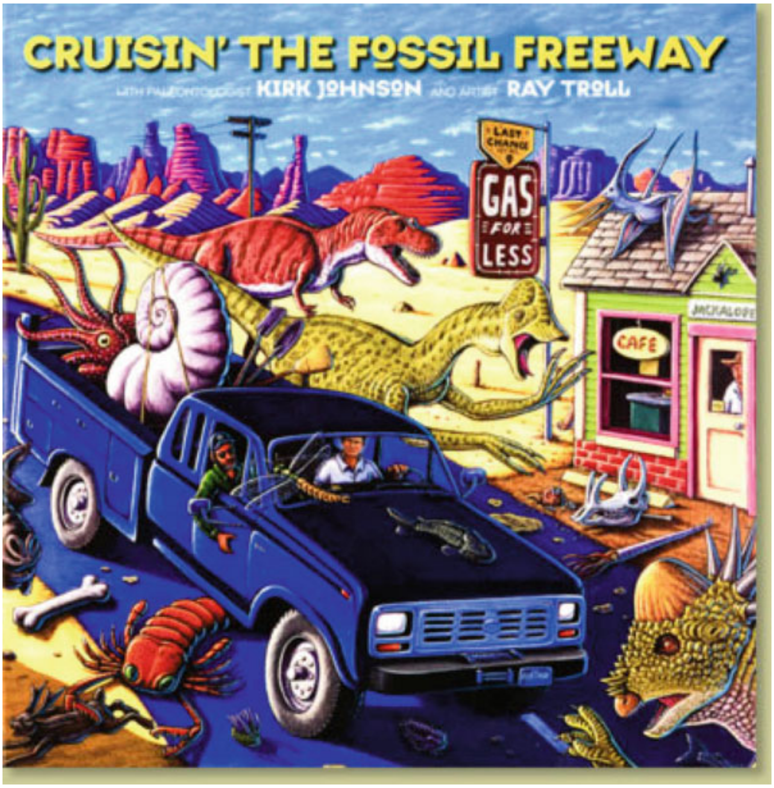

Fig. 1 Johnson and Troll's (2007) book provided inspiration for the Fossil Freeway project in the History of Life course. The project integrated both local fossil collecting and investigation of fossils on display at local informal educational sites (Image courtesy of Fulcrum Publishing)

the local landscape had the greatest effects on their perception, content-specific knowledge, and affective responses toward geoscience themes and issues (Clary and Wandersee 2006). Therefore, in our subsequent research, we tapped into our students' local environments. However, this became a more challenging task within online environments. Although geoscientists often rally around the slogan that "geology is best taught in the field," this can become a difficult undertaking when the student population is geographically widespread.

In order to incorporate field-based learning in online classrooms, we designed autonomous local field assignments for our students. We first employed these inquiry-based student-directed research projects in our online classrooms in 2006. We required students to conduct field fossil investigations within their local field areas and procure and identify fossils (Clary and Wandersee 2008a). We next extended fossil investigations for online students to include informal educational settings where fossils were displayed, such as museums, fossil parks, university galleries, and national parks (Clary and Wandersee 2009, 2010b). Investigations of both field-collected and informally displayed fossils resulted in positive learning experiences within online science courses. Students exhibited increases in content as well as affective learning gains, which were demonstrated by their positive reflections toward course material and delivery.

In this project, we continued our investigation into the use of inquiry-based paleontology research in online students' local environments. We used both field-collecting opportunities and fossils displayed at informal education sites to provide local paleontological context for our students. Students then used the data gathered to recreate the geologic history of their local area through paleoenvironmental reconstruction, and finally applied their content learning by developing activities for their individual classrooms.

2 Motivation and Rationale for This Project

Our geoscience education research is guided by the learning theory of human constructivism, as originally proposed by Novak (1977). Based on the work of cognitive psychologist David Ausubel (Ausubel 1963, 1968; Ausubel et al. 1978), and built upon Novak's pioneering approach to science education research (Novak 1963), human constructivism has been widely researched and expanded (Mintzes et al. 1998, 2000), as well as translated into several languages.

Human constructivism advocates a "less is more" approach in science education, to encourage quality over quantity and understanding over awareness (Mintzes et al. 1998). The goal is to promote conceptual change in learners, who form increasingly powerful knowledge representations as they connect new concepts in substantive ways to prior knowledge and experience. Ausubel acknowledged that the most important factor in instruction is what a learner already knows. Wandersee (1986) restated this as "The most important things students bring to their science classes are their *concepts* [italics added]" (p. 581).

Successful science education scaffolds, or builds, an integration of thinking, feeling, and acting within a learner (Gowin 1981) and anchors these new concepts within existing knowledge structures. In order for *meaningful* learning to occur, students must monitor and take control of their learning (Novak 1998; Novak and Gowin 1984). This process, which is often termed "metacognition," involves the knowledge, awareness, and control of the learner over the learning process (Gunstone and Mitchell 1998). Furthermore, when learners are aware that knowledge is not static, they can engage in what Langer (1997) termed *mindful* learning. This type of learning contrasts the meaningless memorization of terms without a context, in which students are unaware that information changes.

The learning theory of human constructivism supports inquiry-based learning and active-learning strategies whereby learners connect new concepts to their existing frameworks through their experiences. DeBoer (1991) recognized that one of the primary goals of science educators since the 1950s was an incorporation of inquiry within learning experiences. Inquiry exercises can also result in more positive affective outcomes for learners (Lord and Orkwiszewski 2006). Active learning, in which students are engaged in the research progression, can provide more authentic experiences and better understanding of the research process (Felzien and Cooper 2005; Hemler and Repine 2006). Several research studies affirmed the benefits of active and student-centered learning (McConnell et al. 2003; Lawrenz et al. 2005; Michael and Modell 2003).

2.1 Informal Science Education

While it seems obvious that informal education, or nontraditional learning outside the classroom, provides the default learning process for adult learners, it is less intuitive that school-age students also typically engage in informal science learning more often than science learning in traditional classroom settings (Falk and Dierking 2002). Informal or free-choice learning is an important venue for students (McComas 1996, 2006; Wandersee and Clary 2006), and researchers have investigated the theoretical bases supporting learning outside the traditional classroom (Anderson et al. 2003; Falk 2001; Falk and Dierking 2000; Meredith et al. 1997; Orion and Hofstein 1994; Rennie and Johnston 2004). Informal learning environments can supply an interdisciplinary "big picture" for students (Clary and Wandersee 2009), result in holistic learning experiences (Bernstein 2003), and supply environmental context and land ethic (McLaughlin 2005; Roy and Doss 2007). Informal learning instruction can also result in significant science concept gains for students (Elkins and Elkins 2007). Informal educational sites can be used to enhance and extend learning outside formal classrooms, especially if lessons are interdisciplinary, integrate the local environment, and have a specific focus (Clary and Wandersee 2009).

Although the incorporation of examples with exotic, far-away places may capture students' attention in the classroom, our sense of place research revealed that the *local* landscape had the greatest impact on students' content knowledge, perception, and attitude toward science subjects (Clary and Wandersee 2006; Wandersee et al. 2006). However, "local environment" can have a different meaning for geographically dispersed students enrolled in online science courses.

2.2 Online Science Learning

Although science learning in online environments was not immediately embraced by instructors and practitioners, many students—including practicing science teachers—now choose online environments to further their science content knowledge. Several studies affirmed that online courses can be effective learning environments, but this is dependent upon instructional delivery (Means et al. 2009; Tallent-Runnels et al. 2006). Research specific to *science* learning also confirms the potential effectiveness of online science instruction (Clary and Wandersee 2010a; Johnson 2002; King and Hildreth 2001). While early attempts at online science teaching focused primarily on content without an implementation of active-learning strategies, research studies documented that inquiry-based, active-learning strategies can be successfully implemented in online science classrooms to reveal and reinforce the methods by which the body of science progresses (Clary and Wandersee 2008a, 2010a; Gilman 2006).

2.3 Fossils as an Effective Portal for Science Learning

Fossils can be utilized as an interdisciplinary portal through which several scientific constructs can be addressed, including evolution, geologic time, and fossilization processes (Clary and Wandersee 2007). Unidentified fossils can engage students, as well as the public (Burr et al. 2003). Marquee fossils, or fossil specimens with distinctive characteristics, invite an interdisciplinary geobiological investigation into changes over geologic time (Clary and Wandersee 2008b). If locally acquired, Marquee fossils can be effective at illustrating local environmental changes and the accompanying progression of life forms in an area (Clary and Wandersee 2008b).

We implemented our first fossil inquiry-based, active-learning investigation in an online environment in 2006 (Clary and Wandersee 2008a). Practicing teachers enrolled in an online graduate-level paleontology course were directed to locate, procure, and identify fossils within their local field areas. This culminating activity required student synthesis of course content as well as individual application to local, informal environments. Although instructor flexibility was required, online students performed significantly better in this activity than in other assignments and self-reported positive learning attributes toward the project in an anonymous, end-of-semester survey (Clary and Wandersee 2008a). Additionally, 63 % of students demonstrated the ability to geologically synthesize course content in a field environment (Clary and Wandersee 2008a).

Although this first online fossil investigation was successful, we modified fossil investigations in 2007 and 2008 courses to incorporate informal learning sites where fossils were on display, as opposed to student-collected specimens in local field areas. This amendment was made because some students encountered difficulties in field-oriented investigations, either through weather conditions or physical impairments. Students investigated local fossils (i.e., collected from geological strata within their local environment) at museums, fossil parks, and university galleries and synthesized paleoenvironmental interpretations that the fossils supported. Positive learning outcomes were exhibited: The paleoenvironmental investigation helped students to integrate course content, and the informal fossil field investigations impacted their formal geoscience learning by providing an interdisciplinary "big picture" and relating content information to the local environment (Clary and Wandersee 2009, 2010b).

3 Methods

In this research study, we investigated the effectiveness of local, student-directed research activities that incorporated fossils from both informal field-collecting sites (Fig. 2) and educational sites, such as museums, university galleries, and fossil parks, to synthesize two paleoenvironmental reconstructions of students' *local* areas. Our research study was conducted over three semesters ($n = 15$, 14, 7) in the graduate-level paleontology course, History of Life. (The smaller student enrollment in 2011 was caused by late posting of the course.) This course is administered entirely online through a distance learning master's program at a research university in the southern USA. As part of the Teachers in Geosciences (TIG) program, this course's student population is primarily composed of practicing teachers, mostly residing in the continental USA. Administration of course content occurs through streaming video presentations, textbook and autonomous laboratory exercises, and electronic communication in the form of online discussion boards, electronic chat, and e-mail. The only exception to TIG online coursework is a capstone field course in which students can apply the geosciences content knowledge that they accumulated during the program. Through the TIG program, practicing teachers can earn a non-thesis master's degree while increasing their geoscience content knowledge.

Fig. 2 Informal collecting sites can include roadcuts or local outcrops, such as this Cretaceous exposure. Here, middle school science teachers enrolled in a professional development program collect local fossils in an attempt to reconstruct the local geologic history of their state

As an advanced course in the TIG program, History of Life is available as an elective course for second-year master's students, as a substitution for Earth History for those students with a more extensive geology background, or as a course elective in a Master's Plus 30 program. Therefore, students who enroll in History of Life have experience as online learners as well as a solid geoscience content background in geology, meteorology, and oceanography.

The course content is divided into four quarters during the semester. Each quarter is accompanied by a project assignment in which students complete laboratory exercises and conduct research projects. While laboratory exercises may include topographic map analysis or an investigation and identification of fossil specimens provided with course materials, research projects involve an in-depth investigation of specific topics and application of this research within the students' own classrooms. For the projects, students are not only required to produce a research report, but they must also design activities with the assigned content for their individual K-12 classrooms. Activities must represent effective learning opportunities and address required state and/or national science objectives.

Examples of History of Life research projects include investigations into microfossils, ichnofossils, stromatolites, petrified wood, history of dinosaur science, and fossil dichotomous key construction. In the fourth quarter, laboratory exercises are omitted entirely and the assignment focuses strictly on fossil procurement and identification within each online student's local environment, and the subsequent application of this content into students' individual classrooms.

At the end of the semester, when grades are not affected, we invite students to participate in an anonymous, end-of-semester survey that we designed to provide feedback about student perceptions of the course content and assignments. We utilize the anonymous feedback to inform future modifications to the course in order to optimize our online classroom and achieve maximum learning benefits for our students. Therefore, based on students' opinions and recommendations, the final fossil project and its relationship within the History of Life course is altered to increase student science learning and satisfaction.

3.1 The Fossil Freeway Project

We used the positive results of our earlier History of Life fossil investigation projects (Clary and Wandersee 2008a, 2009, 2010b) in the development of the Fossil Freeway project. Implemented across three semesters of the course ($n=15$, 14, 7), the Fossil Freeway project integrated a combination of field-based fossil procurement and investigation of locally collected fossil specimens on exhibit at national and state parks, university museums, and other informal educational sites. Additionally, the project capitalized on the success of Johnson and Troll's (2007) *Cruisin' the Fossil Freeway*, an adventure in which a paleontologist and an artist take a scientific sight-seeing journey across the western USA in search of fossil specimens—both in the field and informal educational venues (Fig. 1).

3.1.1 The Assignment

When we first assigned a Fossil Freeway project in 2009 ($n = 15$), it was the culminating activity of the semester. Previous quarterly application projects included investigations into amber, Diatomaceous Earth, and stromatolites, in conjunction with laboratory assignments (e.g., fossil identification, topographic map interpretation). The Fossil Freeway project, however, was assigned as the only component of the last quarter's laboratory requirement. Because of its requirements and time involvement, we announced the project early in the semester and posted the assignment file on the course website.

The Fossil Freeway (Appendix 1, 2011 version) originally required students to locate and include a minimum of 12 fossil specimens in their project, representing 12 different species and 5 different phyla or plant divisions. In locating and/or procuring local specimens, a minimum of three informal educational collecting sites were required. This Fossil Freeway project integrated both a fossil collecting aspect (Clary and Wandersee 2008a, b) with an informal educational site display (Clary and Wandersee 2009, 2010b). Although some students resided in similar geographic locations, duplication of informal educational site and/or collecting sites was not permitted. However, students were able to focus on different fossil displays within the same institution (e.g., the American Museum of Natural History could be used by two different students if one focused upon the Pleistocene fauna and another focused upon the Paleozoic marine invertebrate display). Informal educational site choices were posted on an online discussion board as they were student chosen and instructor approved in order to avoid site duplication. Students also provided a general description of the informal educational sites of their project in their final Fossil Freeway project report.

In order to verify that the field experience was conducted during the course semester, students were instructed to document each fossil specimen through photography. At least one photograph of each specimen had to include the course logo, as well as a common object for scale. Each year, the course logo was a modified version of an unofficial Geosciences Department logo, with the course year noted on the image (Fig. 3). The logo was only available through the course website and ensured that the student photographed the fossil during the current semester. Objects commonly used for scale included either a red or yellow pencil.

After procuring and/or locating specimens, students then had to identify the specimens according to their phylum, genus, and hopefully, species. Specimens collected in the field were allowed more identification leeway than specimens on display at an informal education site, where fossil descriptive information was included on signage and/or specimen cards. As a result, for museum specimens, students had to include an extended discussion of the distinguishing features of the fossil that warranted its classification. For fossils collected in the field, emphasis was placed on the student's explanation or rationale for the identification. Even if the student misidentified the specimen, she/he could still receive full credit if she/he provided an accurate explanation that supported her/his identification. No student had three sites where fossils were completely identified for him/her. At least one site

Fig. 3 The course logo that had to be included in the fossil photographs for the Fossil Freeway project included the Department of Geosciences "Bully" logo with the year of the course appended to the diagram (Image courtesy of Brenda Kirkland)

had either no fossil identification (e.g., a field-collecting site) or minimal identification (e.g., display cabinets in a university gallery, fossil park signage boards).

In addition to investigating a minimum of three collecting sites and/or informal educational sites, the student also had to ensure that the fossils represented a minimum of two paleoenvironments for the local area. Using the 12 local fossils as a guide, the student next had to reconstruct these two paleoenvironments, identifying the geologic time range and the landscape's local features at that time. A local fossil freeway map, similar to those produced in the Johnson and Troll (2007) text, was encouraged, but not required.

This Fossil Freeway project differed from the earlier investigations of fossils displayed in informal educational sites in that the student-examined fossils had to have been collected *locally.* Although the previous informal investigations had not required that the fossil specimens be representative of local paleoenvironments, the Fossil Freeway project added this criterion. This was done in order to focus student attention upon the local environment. Interestingly, the earlier student projects had included local paleoenvironments even though it was not required (Clary and Wandersee 2009, 2010b).

The second part of the Fossil Freeway project involved the application of the fossil research to each student's own classroom. Since the majority of the students enrolled in the course (as well as the Teachers in Geosciences program) are practicing teachers, the students had to develop a mini-unit for their individual classrooms that implemented the fossils and/or paleoenvironments they researched. Each student had to identify learning objectives individualized to his/her own classroom and develop classroom activities that addressed these objectives. Students also had to identify their individual US state's objectives or benchmarks and the National Science Education Standards (National Committee on Science Education Standards and Assessment 1996). The mini-units had to incorporate more than one learning style (e.g., kinesthetic, auditory), higher order thinking skills (e.g., synthesis, application, evaluation), and active-learning strategies (e.g., student-directed activities, problem-solving investigations, inquiry investigations). The Fossil Freeway project required that at least one assessment tool had to be included in the mini-unit.

Projects were submitted on the online course website, through an assignment tab. Students could submit one large file or separate the project into manageable components when uploading the files. Weighted at 10 % of the final course grade, we assessed the Fossil Freeway project with a checklist and a rubric (Appendix 2). In later versions of the project, the number of required fossil specimens was reduced to 10 (in 2011), and the other quarterly exercises were selected according to their effectiveness to aid in the final local paleoenvironmental reconstruction and fossil identification. Changes were guided by the anonymous student feedback from the earlier 2009 Fossil Freeway project and eventually by the 2010 feedback for the 2011 Fossil Freeway assignment. Therefore, in 2010, other quarterly assignments included local petrified wood investigation, a MicroWorld project (with attention to paleoenvironmental reconstruction through microfossils), and the production of a dichotomous key. In 2011, the quarterly projects included MicroWorld and the dichotomous key production, but the petrified wood assignment was replaced with a local ichnofossil (trace fossil) investigation.

4 Outcomes of the Fossil Freeway Project

Students enrolled in the History of Life course over the 3 years of this research (2009, 2010, 2011) represented different geographic areas of the USA, but larger student percentages were located in the northeastern USA and California (Fig. 4). The past informal education fossil projects had previously verified that this did not present a problem, as students from these areas who investigated fossils through museums, university galleries, state parks, or other display sites did not encounter unusual difficulties in choosing unique locations that differed from their classmates (Clary and Wandersee 2009). Likewise, student selections of informal sites for the Fossil Freeway project did not present difficulties, even when several students resided in the same state (Fig. 5).

In the analysis that follows, we use the student projects from 2009, 2010, and 2011 in our assessment of the effectiveness of the Fossil Freeway project, as well as scores from the quarterly projects, midterm, and final examinations. Additionally, anonymous student feedback from the end-of-semester surveys provided data on the value of the project and its reception among students. Because this feedback was used to improve course content presentation and optimize learning, the 2010 and 2011 History of Life courses were not direct replications of the 2009 course. As a result, a direct comparison of all student assignments and assessments is not possible throughout the 3 years of this investigation. However, we utilize data from all 3 years of the Fossil Freeway investigation to probe the project's effectiveness.

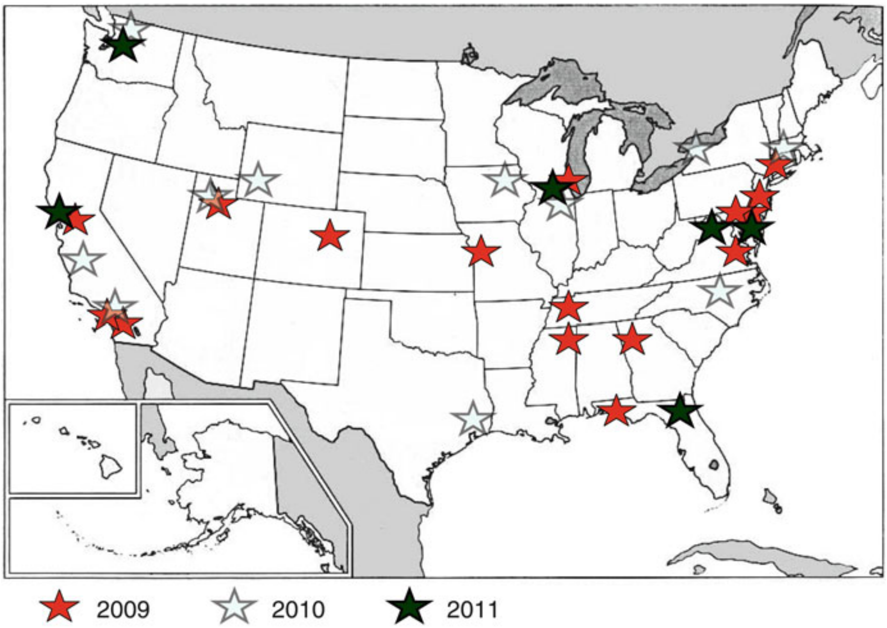

Fig. 4 The geographic locations of students enrolled in the 2009, 2010, and 2011 History of Life courses are shown above. Because of state incentives for master's degrees, and/or inclusion of Earth Science content in the state's required curriculum, teachers from the northeastern USA and California are well represented in the course

Fig. 5 Informal site locations did not present obstacles for students enrolled in the History of Life course, even in geographic regions where multiple students in a course section resided. Here, a student stands near Sharktooth Hill in Bakersfield, California (Photograph courtesy of Kimberlie Theis. Reprinted with permission)

Fig. 6 Students in the History of Life documented their collected fossils through the class logo and the designated object for scale. In these photographs, a student presented *Conus sauridens*, an Eocene cone shell he collected in an Eocene formation in Texas, USA (Photographs courtesy of Andrew Vines. Reprinted with permission)

4.1 Student Performance on Fossil Identification

Problematic project scores were primarily caused by the failure of a few students to submit a passing project for the History of Life Fossil Freeway assignment (2009, $n=2$; 2010, $n=2$; 2011, $n=1$). Once these student data (or more accurately, omissions) are removed from the data set, we encountered very few misidentified fossil specimens. Figure 6 provides an example of a fossil, collected and identified by a student in the 2010 class.

The 2009 students encountered the most problems with fossil identification, but the errors were largely minor ones. For example, one bryozoan was incorrectly identified as *Rafinesquina*, and two students encountered difficulties with species identifications of brachiopods. Only one student experienced consistent issues with identification (5), including bryozoans and brachiopods, as well as a failure to recognize that crinoids were echinoderms.

In 2010, we verified only one misidentification. Although the student correctly identified an ichnofossil as a burrow, the shape did not indicate the burrowing shrimp *Thalassinoides*, as suggested by the student. Additionally, there were some suspect identifications that could not be confirmed. One student identified a fossil as an annelid. However, it appeared suspiciously like an iron oxide infilling of a mold or a possible concretion, although we could not directly verify our interpretation.

Likewise, we were uncertain of the definitive identification of a bryozoan as *Tubulipora* because of the clarity of the fossil photographs.

The 2011 Fossil Freeway project changed from previous years in that the number of required fossil specimens was 10 per student. We only encountered two problematic identifications with this class. *Halysites* was incorrectly identified by one student as a sponge. Another student identified a specimen as a sponge, but we were not able to confirm that the sample contained fossilized organic remains as opposed to a secondary sedimentary structure.

Considering that History of Life students each identified 12 fossil specimens in 2009 and 2010, and 10 fossil specimens in 2011, the identification and discussion of fossil specimens, including student-collected ones, was excellent. With the omission of partially submitted or missing projects, 31 students were responsible for procuring, locating, and identifying a total of 360 fossils ($n = 156, 144, 60$). Even if we consider our questionable identifications as incorrect student responses, the 12 problematic specimens, from 3 years of online fossil research, represent a total of less than 3.5 % of the total fossils identified.

4.2 Student Performance on Paleoenvironment Reconstruction

Unlike our previous paleontology projects for online classrooms, the Fossil Freeway project *required* that the fossils selected for investigation were collected from within the student's local environment. We added this criterion to focus attention upon the local landscape, which typically has the greatest influence on our students (Clary and Wandersee 2006). The student projects that were submitted did, in fact, effectively interpret past geologic environments of an area through its fossils. The 2009 students successfully reconstructed Cambrian, Ordovician, Silurian, Devonian, and Carboniferous marine environments, as well as a Permian terrestrial environment to represent paleoenvironments of the Paleozoic Era. Cretaceous marine environments were successfully reconstructed for the Mesozoic Era, and students focused on paleoenvironments of the Cenozoic in the form of Eocene, Miocene, and Oligocene marine environments and Pliocene and Pleistocene terrestrial environments.

In the 2010 course, a wide variety of paleoenvironments were again successfully reconstructed through student-selected fossils: Paleozoic Era marine environments were described from the Cambrian, Ordovician, Devonian, and Carboniferous, while Devonian terrestrial and Carboniferous swamp paleoenvironments were also included. The Mesozoic was represented by Triassic and Jurassic terrestrial and Cretaceous marine paleoenvironments, while the terrestrial Cenozoic paleoenvironments were described for the Eocene, Miocene, and Pleistocene.

Although the 2011 course had a reduced student population, there were still a variety of paleoenvironments submitted in the Fossil Freeway project. Cambrian, Silurian, Devonian, and Carboniferous marine environments represented the Paleozoic Era, while the Mesozoic Era was reconstructed through a Cretaceous terrestrial paleoenvironment. Finally, the Cenozoic was represented with Eocene marine, estuary, and terrestrial paleoenvironments, as well as Pliocene marine, Miocene bay, and Pleistocene terrestrial reconstructions. No problematic areas were uncovered in the student reconstructions. A few instructor comments on these submissions encouraged students to more thoroughly incorporate local fossils to support their interpretations, but all student-submitted reconstructions were essentially correct for the local areas described.

4.3 Student Performance on Fossil Freeway Classroom Application

Our students consistently produced informal and traditional activities with local fossils that provided excellent opportunities for classroom learning. This is consistent with our earlier investigations (Clary and Wandersee 2008a, 2009, 2010b); our own students consistently were able to research local fossils, interpret past paleoenvironments, and then apply this content at the appropriate level for their own student populations.

For example, our 2009 students developed activities with locally collected and/or displayed fossils for both middle and high school environments. For middle school (US grades 6–8), some of the local fossil investigations included

- Classroom “fossil dig” reconstructions with local fossils in a Plaster of Paris matrix
- Field excursions to museums with scavenger hunts and selected activities at each site
- Field excursion dinosaur track field sites with collection of footprint data and identification of potential track makers upon return to the classroom
- Investigation of dinosaur tracks, and calculation of the animals’ height and speed from site-collected data
- Student paleoenvironmental reconstruction of their local area through websites and classroom fossils
- Virtual field trips utilizing museums’ Internet websites

Some of the high school activities (US grades 9–12) included field trips to informal fossil collecting sites and comparison of fossil assemblages between sites and classroom identification of local fossils through teacher-constructed dichotomous keys.

The 2010 students produced similar activities that involved identification of local fossils within a classroom setting, or a variety of field trips and informal site investigations as classroom activities. However, one student developed a classroom investigation with local fossils that not only involved identification but also preparation: middle school students processed and mechanically separated microfossils from macroinvertebrates, using common materials (e.g., ladies’ stockings, wire mesh screen).

Although the 2011 class size was small, several unusual classroom application activities were developed within the Fossil Freeway project. One student designed an activity that calculated the volumes and maximum organism sizes based on classroom field-collected ichnofossil data at a regional preserve (US high school level). Another creative activity involved the artistic reconstruction of an extinct local organism and the development of a fictional account of the adventures of the organism (US middle school level). While one student developed an assignment involving the creation of a brochure or short video that documented the local area in its geologic past (US high school level), yet another high school activity involved a "chronotourism" activity in which climate changes in the local environment were documented throughout the area's geologic history.

In all 3 years of the project, students were able to produce a variety of assessment items, incorporating performance assessments, portfolios, projects, and traditional examinations. Because time constraints prevented direct implementation of these projects within our students' individual classrooms during the semester of study, we are unable to report whether these projects were well received by the K-12 students for whom they are intended. However, we designed the guidelines of the required mini-unit component to facilitate implementation in our students' K-12 classrooms in the future.

5 Evaluation

5.1 Student Integration of Paleontological and Interdisciplinary Science Concepts

A direct comparison between the History of Life assignments in all 3 years of this research investigation is not possible, since changes were made to the course in 2010 and 2011 in an attempt to optimize content and delivery. Additionally, changes in percentage weighting in the 2010 course do not facilitate direct comparison, except for the fourth quarter Fossil Freeway project. However, when we investigate the class performance across all 3 years in the Fossil Freeway project, the average is a respectable 90.9 %. Although not significant, the project exhibited slight positive increases from 2009 through 2011, with a 90.32 average in 2009, a 91.38 average in 2010, and a 91.5 average in 2011. A quick comparison of quarterly project and examination scores with 2009, 2010, and 2011 course sections reveals that the Fossil Freeway project was one of the higher scoring assignments.

The quality of the Fossil Freeway projects is, we propose, more indicative of successful synthesis of the course material within the project submissions. Not only did students perform well on fossil identifications and paleoenvironmental syntheses, but several students also developed the optional Fossil Freeway map of their local areas. Some students chose to produce a Fossil Freeway map with mapping software, overlaying their sites with clickable information embedded within the website. One student reconstructed Devonian and Pleistocene environments via specimens collected at a roadcut at a railroad bed, a fossil reef, the Buffalo Museum of Science, and Penn Dixie Paleontological and Outdoor

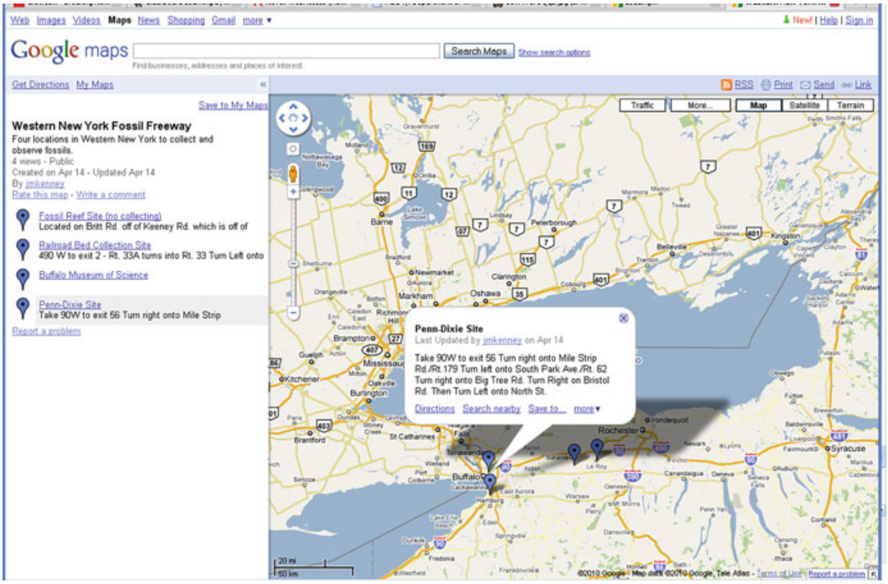

Fig. 7 This Western New York Fossil Freeway map utilized the free software, Google Earth. Each of the field sites and informal educational venues is noted on the map, with specific directions available (Fossil Freeway map of Western New York developed and courtesy of Jennifer Kenney. Reprinted with permission)

Education Center, all located within upstate New York, USA (Fig. 7). The electronic map reconstructs the journey through this area and provides basic information to a potential geotourist.

Some of the submitted Fossil Freeway maps were hand-drawn by students (Figs. 8 and 9) in a successful synthesis of course content and project assignment. The Fossil Freeway of North Carolina (Fig. 8) locates the informal sites visited by the student, some of the basic geologic features of the state, and a few of the fossils (trilobites, rugose coral, sharks' teeth, ammonite) personally located, identified, and described by the student. The map successfully incorporates course content (geologic features, fossil information), the informal investigation (sites chosen that display fossils), and the paleoenvironmental journey of North Carolina during the Ordovician Period, the Cretaceous Period, and more recent Paleogene Period.

Likewise, a student reconstruction of the Fossil Freeway of Washington State, USA, reproduces the fossils investigated in the assignment, geographically positioned where they were collected (Fig. 9). The student identified the collection sites and added major Interstate Highways in order to assist a geotourist with a future fossil road trip within the state. Fossil Freeway maps generally not only represented a synthesis of the material but also demonstrate creative solutions. These diagrams distill much course information in an optimized visual display.

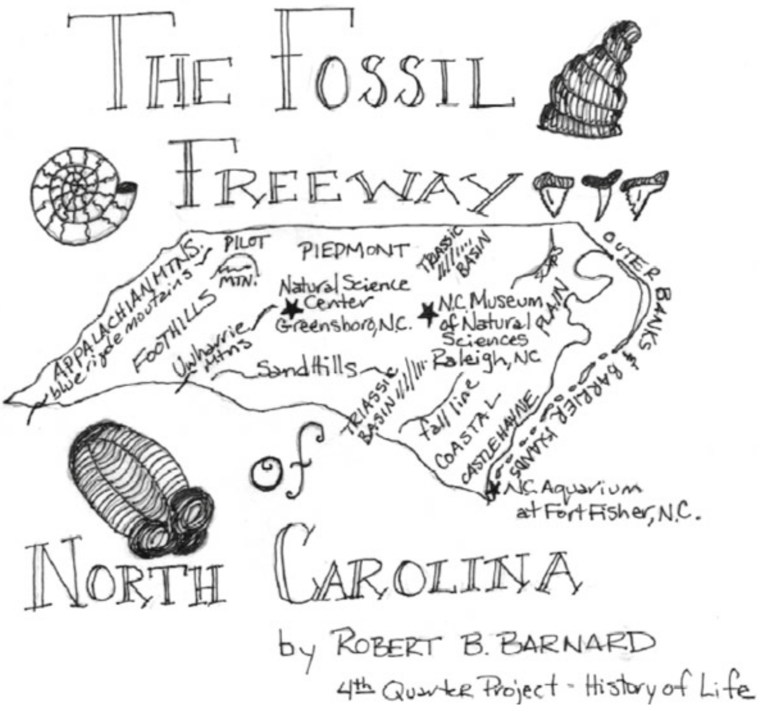

Fig. 8 The Fossil Freeway of North Carolina depicts some of the fossils of the state, including trilobites, ammonites, and shark's teeth (Fossil Freeway map of North Carolina courtesy of Ben Barnard. Reprinted with permission)

5.2 Student Perceptions

We subjected end-of-semester survey responses from 2009, 2010, and 2011 to content analysis (Neuendorf 2002). These end-of-semester surveys consisted of 18–21 questions, with four open-ended questions directly probing the Fossil Freeway project (Table 1). Survey responses were individually coded and analyzed and placed into the categories that emerged. We determined inter-rater reliability at 92 % for all coded responses over the 3 years of the Fossil Freeway project. We separately analyzed each year's survey data of the Fossil Freeway project, along with general course feedback, via the end-of-semester surveys. This is because the analysis is ongoing, and the feedback from each year informs the course development for the next year.

Several stable themes emerged, many of them reiterating the importance of inquiry-based, hands-on learning within the local environment; reinforcement of course content; and applicability to our students' individual classrooms. Content analysis also revealed consistent threads for course improvement, including increased applicability of quarterly projects to the final assignment, time demand, and peer sharing of projects. We discuss the results of the anonymous survey content analyses by project year, since the results of these surveys resulted in modifications for the subsequent year of the course.

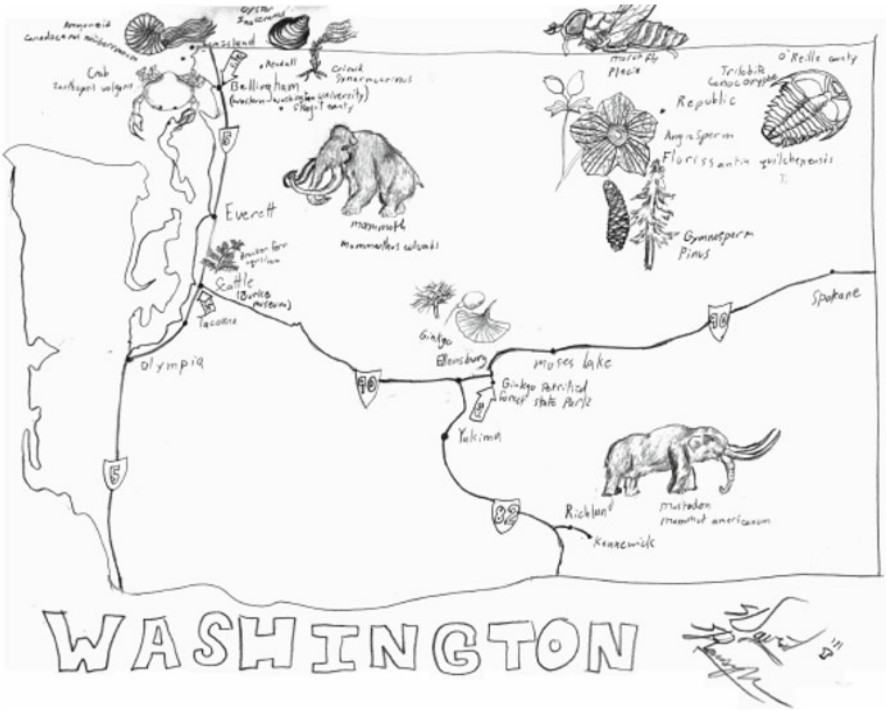

Fig. 9 This Washington State Fossil Freeway map includes several of the plant fossils for which the state is famous, in addition to some of the Pleistocene fauna (Fossil Freeway map of Washington State courtesy of David Ramseyer. Reprinted with permission)

Table 1 End-of-semester survey, Fossil Freeway questions

Item	Question
FF a	Did you find that you were able to use the previous quarterly research projects in your final Fossil Freeway project?
FF 1	Consider your Fossil Freeway project: What is your perceived value and impact of the informal science education sites/fossils to your formal geoscience learning?
FF 2	What do you think student interest level would be for your developed Fossil Freeway investigation activity, or a similar activity, in your own classroom?
FF3	What was the most valuable learning experience you had during your Fossil Freeway project? What do you think would be the most valuable learning experience for your own students with this project?

5.2.1 Content Analysis of End-of-Semester Surveys, Year 1

All students ($n=15$) participated in the 2009 end-of-semester survey. Content analysis of the first end-of-semester anonymous surveys for the 2009 History of Life course revealed several prominent themes from the final Fossil Freeway project, including (1) its value in promoting a regional connection for students, (2) the practicality of the project for its direct implementation within the students' individual classrooms, and the (3) benefit of active-learning and field-based learning activities, especially within the online classroom.

The most prominent theme to surface was that the Fossil Freeway project facilitated a regional connection of content to students' local areas. This connection included the identification of fossil collecting sites and informal education facilities that our students could use in their own classroom excursions and the illustration of the environmental changes of their local areas throughout time. Several of our students remarked that the project made them aware of the fossils and facilities of their local areas: "My most valuable experience was finding the new science museum about an hour from my school that none of us [teachers] had ever heard of before (it opened just 4 months ago). This was a wonderful place, and I know we'll be taking a field trip there [with our students] next year." Another person remarked that the Fossil Freeway project "provided me with an awareness of the local fossil sites, paleoenvironments, and extinct organisms that lived in my area." Other students noted that an asset of the project was in facilitating the regional connection between past geologic environments, illustrating a change over time: "I always think of Utah as a land-locked desert when it has varied greatly over time! What a great activity!" Several students echoed this sentiment, including one who stated that the most valuable experience of the course was in "learning the geology and past life of my local area.... For my students, it would be the evidence of extinct animals and changes in the landscape."

The value of active-learning strategies and field-based learning was also a common thread of the Fossil Freeway project's feedback. Students stated that "you always learn more when you do the discovering for yourself" and mentioned the importance of "hands on experience and delving more into this aspect of the geosciences. I will definitely ramp up my encouragement for students to do field work and projects."

The third major theme to emerge through content analysis was the practicality in utilizing this type of activity within K-12 classrooms. The subject of local fossils was perceived as interesting and of high value for K-12 students. Additionally, our students recognized that fossils could serve as a portal to introduce several fundamental scientific constructs. ("Ancient fossils are inherently fascinating, and it is easy to interest people in science and geology this way…. It is also a great way to get across fundamental concepts like geologic time and evolution"). One student remarked that the fossils recovered through the Fossil Freeway project were already being utilized in the classroom: "I can use the stories behind their [fossils] discoveries to introduce unlimited topics. I have already used several of those that I discovered on this project in the classroom already." Several students remarked that investigating ancient, local life forms would be popular with their own students. One student remarked, "Getting to actually touch the [dinosaur] tracks makes such a difference with 10 year olds." Another student stated, "Getting them to collect their own fossils would be an awesome opportunity that almost all of my students would enjoy."

There were other subthemes that materialized from the 2009 content analysis as well. These included the flexibility of the Fossil Freeway project for interdisciplinary studies, the advantages of collecting personal fossils, and the meaningful learning that resulted with the self-directed research in the online classroom, as opposed to traditional content presentation and assignments. Several students remarked that multiple benefits resulted from collecting and personally owning a small group of fossils. One student stated, “There is a tangible thrill that comes from finding fossils on your own. I felt a great sense of accomplishment when I realized that I could actually identify many of my fossils.” Another student concurred: “I have no illusions about being a paleogeologist, however digging fossils with my own hands, having found the sites myself, was exhilarating and created a tangible connection to the course material.” The reinforcement of the course material for an interdisciplinary “big picture” was also noted. One student remarked that the Fossil Freeway project “reinforced many concepts from the two geology courses I had taken and really helped make sense of the history of life at a local level.” Several students affirmed that the research activity was a valuable experience for an online course. Students remarked, “I really liked doing the research”; and the best part of the course was “the ability to do real research, instead of just looking things up. I learned a lot this semester!”

We also received feedback for Fossil Freeway project improvement, with the development of two themes for course improvement. The Fossil Freeway project’s excessive time demand was mentioned most frequently. Comments included the project’s “very time-consuming” nature, and that it was “excessively demanding in its requirements” and took “an inordinate amount of time to complete.” One student suggested that “the assignment is a good idea, but needs to be adjusted to make it more time friendly and learning friendly.” Another student noted, “If the project was not as time intensive and maybe broken out over the semester with the other quartly [sic] assignments, it may work out better. It was nice to see the geology of the area and have a better understanding of the area.” A few students also mentioned a preference for seeing their peers’ final projects, such as “I think that the mini-units would be useful if they were made available to for all of us [sic] to access and share with each other.” Even with the comments about the excessive time demand, 47 % of the students ($n=7$) selected the Fossil Freeway as their favorite project of the 2009 course.

5.2.2 Content Analysis of End-of-Semester Surveys, Year 2

We adjusted our History of Life course and made changes to the Fossil Freeway project based upon the feedback of the 2009 end-of-semester survey. In particular, we designed the first, second, and third quarterly projects to complement the final Fossil Freeway assignment by providing students opportunities to research paleoenvironments through local petrified wood samples and microfossils and designing dichotomous keys that would aid in fossil identification. We also implemented discussion threads in which students posted their projects. This provided a series of units that would be useful for our students within their own classrooms.

We only had nine students respond with feedback for the 2010 end-of-semester survey, which was the lowest participant response (64.3 %) that we encountered in any online course. However, the comments we received were valuable, and we subjected them to content analysis (Neuendorf 2002). Similar themes emerged in comparison with the 2009 students, including (1) the Fossil Freeway project facilitated a regional connection between our students and their local geographic areas; (2) active-learning and field-based projects have high value, especially within the online classroom; and (3) the interdisciplinary nature and summative assignment format reinforced geosciences content and facilitated a "big picture" for the course. Similar to the 2009 survey responses, students most often cited that the primary value of the Fossil Freeway assignment was in facilitating a regional connection between course content and their local geographic area. "The most valuable learning experience was finding new sites to visit and finding new places to take my students," one student remarked. Other students issued similar statements that their local areas contained more fossil sites of which they were previously unaware: "Learning that there are many more fossil sites and outcrops than I knew about previously. The kids would benefit from getting out of the ghetto/barrio." Students remarked they "truly enjoyed learning more about my local area," and that the Fossil Freeway "included the most local paleontology and really got me into the 'spirit' of paleontology." One student looked forward to the end of the semester: "I cannot wait for the summer field studies to be over so I can go get more fossils!" Our students also noted the value of these sites for their own classrooms. ("It would motivate the students to utilize the area resources for fossils").

The active-learning, field-based methodology was also appreciated by the 2010 students, some of which noted that the Fossil Freeway project "gets them [students] out of the classroom and into the field" and "demanded that I get out and explore!" One student remarked that the value of the Fossil Freeway project was "Incredible. I love the way the project gets you to dig (sorry). I will always try to create lessons in this manner from now on." According to one student, the most valuable part of the course was "the hands-on real-life fossil search. It really sparked a true love of fossil hunting and an interest in learning about the past."

Once again, students also mentioned that the informal, self-directed Fossil Freeway field investigations afforded them the opportunity for "seeing the big picture" and bringing the course content "all home and tied it together on a local scale." One student state that this project "allowed us to apply what we were taught in the class room to actual field experience." Another student affirmed that "going to the informal/formal sites provided numerous insights to what we studied in this class."

Three minor themes also developed from content analysis, including the benefit of personally collected fossils, the value of research investigations in online classrooms, and the practical application of the Fossil Freeway project within our students' personal classrooms. One student noted that "actually finding fossils in your backyard really brings the history of life 'to life.' It also helps students realize the Earth has not always been the same." This was perceived as being advantageous to students, in that "one of the hardest things to do is to illustrate a particular fossilized life form to a student body. These sites allow the instructor to illustrate aspects of the fosslization [sic] process as well as show details about the organism's structure that were discussed in class. A picture on a page can NEVER replace a 3-dimensional, once living example!"

Students also affirmed the benefits of research, as opposed to classical presentation and testing of content material. ("I …vote for the application exercises, they felt more like research." "I learn more by doing research....") Many aspects of the Fossil Freeway project were affirmed as being directly applicable to the students' individual classrooms. One student remarked that the personally collected fossils were already in use: "Well I know for a fact they [students] all loved mine!! I also showed my coworkers and they loved it too! I cannot wait to incorporate more into my class."

The content analysis of 2010 responses also revealed that we still had room for improvement. Students mentioned the time demand of the project, but we also realized some gains in the applicability of the three earlier project assignments toward the final Fossil Freeway project. Some of the time-demand comments included that the History of Life course was "more time-consuming than any course I've experienced" or that the Fossil Freeway project "overwhelmed me." One student made an appeal for the future students of the course: "For the sake of future students, please consider cutting something out."

We were pleased to see that we had made some gains in the applicability of the earlier projects toward the final Fossil Freeway project. One student stated that this organization "helped me work smarter, not harder, although it was still hard and a lot of work." Another remarked that earlier assignments supplied "more of the 'knowledge base'…than the actual 'use of information.'" Especially encouraging was that 78 % of the 2010 students ($n=9$) named the Fossil Freeway as their favorite application project for the course.

5.2.3 Content Analysis of End-of-Semester Surveys, Year 3

In 2011, we utilized the feedback from the 2010 students to again adjust the course assignments. The number of required specimens (and species) in the Fossil Freeway project was lowered to 10 from 12. Additionally, the quarterly projects focused upon ichnofossil and palynology of the students' local regions and the construction of the dichotomous key. Five students (71 %) accessed and provided feedback for the course via the end-of-semester survey. Two very stable themes emerged from content analysis and reiterated the importance of the Fossil Freeway project in promoting a connection to students' local regions and the benefits of active- and field-based learning in the online science classroom. As in previous years, the themes that emerged included (1) the Fossil Freeway project facilitated a regional connection for course content and (2) active-learning and field-based learning techniques are superior methods by which to learn the course content in online classrooms.

Students mentioned that the project facilitated a connection to fossil sites and local resources. One student commented the project "forced me to view and find local resources I would not otherwise have known about. The advanced notice about the requirements was also much appreciated." Another student remarked, "It got me out in the field and to see what my area has to offer in the geoscience field." Likewise, as in previous years, students mentioned how the Fossil Freeway research illustrated the local geographic region's past geologic history and how the fossils helped students "to understand past local environments and understand how ecosystems and the climate were different in the past." One student declared, "I truly enjoyed researching about the paleoenvironment of my area to help me have a better understanding of where I live." Another student wrote, "It really made me think about the way life has changed in my area over time." One teacher noted that the fossil collection "made me look at the areas in a different way. For my students [it] would be the collecting sites, because it would make them look at their own community in a different way, just not what is at the surface." Another teacher confirmed this, noting that the project's value for students "would be for them to realize that the Earth and its inhabitants are constantly changing."

The benefits of active learning and field-based learning emerged as the second strong thread within 2011 students' comments. One student noted that the field-based project gave her/him the "confidence that I could find places I had not been too [sic] and identify (not as well as I would like) what I was looking at, and that I could start to read the story of how and why the fossils were there." Another student affirmed the value of active-learning investigations: "The Fossil Freeway project was an investigative, hands on project. This is an excellent way to learn. It included many aspects of geosciences. Not enough students are going into the geoscience field and I believe projects like this in high school would change this."

The subthemes that emerged from 2011 content analysis included the usefulness of the project within the students' individual classrooms, the hook that personal fossils provide for students, the reinforcement of content that the Fossil Freeway project afforded to students, and the positive attributes of self-directed research in the online classroom. Several students noted that the fossil investigations could be modified for their own classrooms. One student acknowledged, "The exercises were excellent. They will be used on my classes, and modified for what ever I teach." Yet another student noted that "These are things that can actually be used in the classroom and by sharing with others you get more possibilities to try in your classroom." One student stated that the Fossil Freeway project was specifically designed for incorporation within her/his own classroom: "I wrote the activity with the intent to use it next school year. I would like to incorporate the activity into our course work. I think that they would enjoy the chance to investigate and describe their own subject matter."

The 2011 students again affirmed the benefit of hands-on fossil collecting with the "most valuable experience is the collection portion." Another student asked, "What student would not be interested in the opportunity to go on multiple fieldtrips and view and collect their own fossils?"

The students also confirmed that the Fossil Freeway project helped to provide the "big picture" of the curriculum taught in our online paleontology classroom. "The sites I visited really helped me make connections in what I was learning in class," one student noted. Research opportunities were also positively received by the student population, with one student stating that the project "provided an opportunity to apply the research and lab material to a science curriculum. Also seeing what my peers constructed was very helpful." Another student noted that "this project actively involves students in something they feel is beyond them. The great thing is they would find out they can do more then the[y] ever imagined."

Only one student noted the time demand of the Fossil Freeway project with the new, 2011 modified guidelines ("large volume of work"), but all students stated that the first three quarterly projects were helpful when researching and assimilating the final project. The remark, "Fossil Freeway…was a kind of a combination in what was learned in the first 3 [quarterly projects]" generally summed up students' perception. When asked to name a favorite project of the 2011 semester, all students (100 %) chose the Fossil Freeway project.

6 Implications for Wider Practice and Conclusions

Our previous research with Geological Sense of Place revealed that the local landscape had the greatest effect on our student population (Clary and Wandersee 2008a). However, within online environments, tapping into students' sense of place is more difficult when students reside in various geographic areas. Through our initial research with local field investigations in online environments, we discovered that student-directed paleontological research is possible for online students (Clary and Wandersee 2008a). From this initial autonomous student field investigation, we continued our research to optimize active-learning, field-based investigations for meaningful student learning.

Our subsequent investigations included informal educational displays, since some students had difficulties procuring fossils in the field through either physical impairments or adverse weather conditions. The informal field sites were likewise a successful venue, and students were able to utilize publicly displayed fossils to recreate paleoenvironments (Clary and Wandersee 2009, 2010b). Johnson and Troll's (2007) *Cruisin' the Fossil Freeway* became the inspiration to develop a project for the reconstruction of a student's *local* paleoenvironment, through both informally publicly displayed fossils and self-collected specimens.

6.1 Use of Student-Directed Field Excursions Within Online Environments

Throughout this 3-year project, we confirmed that student-directed field investigations in online environments are possible, and that inquiry-based approaches that include students' local environments result in successful outcomes. Student fossil identifications were excellent, and students were able to successfully plan field investigations and integrate fossil specimens with course content to reconstruct local paleoenvironments. Throughout the 3 years of our research investigation, a primary theme that emerged from content analysis of student anonymous survey responses was that the Fossil Freeway project facilitated the local connection between the course content and the students' geographic areas, and this was perceived by our students as valuable. Additionally, the Fossil Freeway project scores were positive when compared against other course project assignments. After modification and optimization, anonymous student feedback revealed that the Fossil Freeway project was the favored project for the *entire* student population in 2011!

6.2 Use of Fossils to Facilitate Science Learning

Our online students affirmed the value of fossils in addressing important interdisciplinary scientific content, including geologic time and evolution. A consistent theme to emerge through content analysis was the positive benefits that resulted from a group of student-collected, personally owned fossils. Our students noted that not only did the fossil collection facilitate their understanding of course content, but the fossils utilized within their individual K-12 classrooms were also well received by their students.

6.3 Summary and Suggestions for Implementation of Inquiry Research Approaches in Online Classrooms

The Fossil Freeway project that we developed in 2009 was modified and optimized in 2010 and 2011 to promote mastery of paleontological content, meaningful learning, and positive affective outcomes within our student population. Using the anonymous student feedback each semester, we maximized the applicability of course projects to dovetail into the final Fossil Freeway project. We also sought to lessen the time demand of the project by reducing the number of required fossil specimens. We added discussion threads in which application projects were shared, resulting in a collection of teaching tools for our student population. With these changes, we observed increasingly positive student reflections throughout this 3-year research investigation. Additionally, the identification of the Fossil Freeway project as the favored project of the course increased from the origin of the project, through 2011.

Content analysis consistently revealed that the advantages of student-directed inquiry field investigations included a connection to the students' local geographic areas, in both current fossil resources and sites and in illustrating the changes of the local environment throughout time. Students also consistently noted the benefits and enjoyment of active-learning and field-based activities in the online classroom, stating that the Fossil Freeway project facilitated a big picture and integrated course content for meaningful learning. The Fossil Freeway activities were also applicable to our students' individual K-12 classrooms.

We propose that inquiry-based approaches that utilize students' local field environments offer a good alternative to the more traditional approaches utilized in online classrooms. Our results indicate that active-learning, field-based investigations maximize science learning and affective student responses. Online students can successfully plan field excursions, procure fossils, identify them, and assimilate content to reconstruct paleoenvironments of their local geographic areas. However, we caution that inquiry projects should be optimized to maximize content integration without unnecessary time demands on the student population. Therefore, streamlined research projects that allow students to apply course content within their local geographic area and actively locate field sites and integrate course content can maximize meaningful learning in the online science classroom. Since personally found fossils result in positive attitudes toward course material and address several interdisciplinary scientific constructs, we recommend their use as a portal for scientific investigations.

Overview

Background and Motivation

– Students' local environments had the greatest impact on their Geological Sense of Place.
– Fossils provide an interdisciplinary portal through which several important scientific constructs can be addressed.
– Autonomous student-directed field investigations within online classrooms can result in positive learning outcomes.

Innovations and Findings

– Online students can successfully plan local fossil investigations, utilizing both informal collecting sites and informal educational displays. Local fossils and field investigations serve as an interdisciplinary portal that integrates course content and promotes a regional connection for the student.
– Local fossils can successfully facilitate local paleoenvironmental reconstructions, supplying an interdisciplinary "big picture" for online students. Individualized, self-directed research in local environments results in creative student projects and positive affective student gains in online environments.
– Structured, online discussion threads facilitate social dialogue and social construction of knowledge between online students. Peer sharing of finished projects links learners from widespread geographical areas in online environments, allowing them to share outcomes and ideas for integrating knowledge in their own classrooms.

Implications for Wider Practice

– Inquiry-based research within online environments results in affective student outcomes in addition to increases in student content knowledge.
– Inquiry-based research approaches should be optimized to minimize the time demand while promoting meaningful learning of the course content.
– Fossil investigations are interdisciplinary in nature and can be used to address a variety of scientific constructs, even within online environments.

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Appendices

Appendix 1: The 2011 History of Life Fossil Freeway Assignment Guidelines

History of Life
4th Quarter Exercise Project
Application and Synthesis
Your Local Fossil Freeway
The Strata that Matter

In lieu of a Brice, Levin, and Smith lab manual component for your 4th Quarter Exercise assignment, you will be responsible for a synthesis and application project. You will be responsible for a "chapter" about *your* local area in which you will be *Cruisin' the Fossil Freeway*.

Use Johnson's and Troll's text as a loose guideline for fossil exploration in your own area. What interesting fossil outcrops, museums, and parks are within driving distance in your part of the country?

You will photograph and discuss fossil specimens that you locate in a minimum of three informal educational sites (museums, fossil parks, university collections, local fossil collecting sites,[1] etc.). In this assignment, you will be applying the knowledge and skills you have acquired in this course to your local paleontological displays and fossil outcrops. You will then adapt the specimens and the informal sites for use in your own classroom. *Your grade for the 4th Qtr Exercises will come from this project*; *there will be no lab manual assignment or 4th Qtr Exercises exam*.

Guidelines for the Project

1. *The specimens*: Each student is required to locate and include a *minimum* of *ten specimens* representing *ten species* and *five different phyla* (Cnidaria, Porifera, Mollusca, Brachiopoda, etc. You may also use plant divisions to count for phyla.) You should use a *minimum* of three *informal educational sites* (local collecting site, fossil park, university museum, Natural History Museum, etc.) Please let me

[1]Remember to always secure the correct permissions before accessing private land. Always follow best safety practices and techniques when collecting in the field!

know if you encounter difficulties in locating informal education sites or fossil outcrops in your area. Specific exhibits at any informal educational site may be used only once this semester. Therefore, if you describe the Mesozoic landscape of your area, and then use fossils from the local natural history museum to illustrate this environment, no other HoL student may use the Mesozoic display at this local natural history museum (but may use the Paleozoic exhibit). Therefore, please e-mail me with your choice(s), and I will send an approval e-mail if the site has not already been claimed by one of your colleagues. (This should only affect a few of you who live in the same general vicinity.) We will post the approved sites on a discussion board so that everyone will be aware of the sites that are already claimed.

(a) Each of the 10 specimens that you include in your project must be photographed. Include in the photograph (1) a standard yellow #2 pencil for scale, centered at the bottom, and (2) the MSU Geosciences Bully logo (with the HoL Spring 2011 annotation) in the lower right of your photographs. The 2011 MSU Geosciences Bully logo is attached to an instructor's message, as well as posted under Additional Resources.

   (i) Please print a copy of the logo to use in your photographs; it should insert into an MS Word file as an image that is **1.3 × 1.72 in.**.
   (ii) You may have to take two photographs—one including the scale, and the other focusing on the specimen—for each fossil. You are required to take at least one photograph that includes the 2011 Bully logo and the yellow pencil for each of the 12 specimens.
   (iii) Please check with the museum/site staff *before your visit* to verify that photography is permitted. If it is not permitted, contact me for additional instructions.
   (iv) ***Never trespass on private property in search of fossils! You must procure permissions before investigating privately owned property.**
   (v) Be prepared to take many photographs if you use museum sites, as photographing specimens behind glass is often tricky. (Place the camera lens directly against the glass, or, if you have a flash that can be angled, aim the light at an oblique angle to the glass surface.)
   (vi) If you do not have a digital camera for this assignment, buy disposable cameras, and when processing your film, have the photographs saved to a CD. This has become a viable, inexpensive option.

(b) Each specimen must be identified according to its phylum, genus, and species in the caption under the photograph.

   (i) Museum specimens will be identified for you. Therefore, you must also include a brief discussion of the distinguishing features of that specimen. (You must discuss why it warrants a particular classification. For example, why is a specimen categorized as Cnidaria, Tabulata, *Halysites*?) Your discussion should include an explanation of the basic, significant morphological features of each specimen.

(ii) For collected specimens displayed in museums or parks, be sure to include only fossils of organisms that either lived in your local area or were collected in your area. (For example, do not include trilobite specimens from Utah, unless you are fortunate enough to live in Utah!)

(iii) For specimens you collect in the field, more leeway is given for identifications. Please identify the specimen as best as you can, and note why you placed the fossil in this category.

1. Each specimen must be identified according to its phylum and genus. Please make an attempt at the species identification. Common or familiar names (such as "chain coral") are encouraged, but not mandatory; however common names do not replace the necessity for scientific ones.
2. There are several fossil texts that can aid you in the identification of your specimens. The "Roadside Geology" series are often good places to start for US locations. The Audubon Society, Simon and Schuster, and the Smithsonian also publish easy-to-use field guides. If you are procuring in a specific area, an internet search might turn up a book on fossils specific to your area.
3. Be sure to reference any source that you utilize in your project.
4. You should explain how you identified each specimen; this should include an explanation of the basic, significant morphological features of your specimen. *Even though you may incorrectly identify some of your specimens*, *you will receive full credit if your explanation supports your identification*.

(c) Each specimen must be identified according to its geologic age. Please include the specimen's period (or epoch for Cenozoic specimens) and an approximate age.

2. *The paleoenvironments*: Your fossil road trip should include general descriptions of your area at two different geologic times. Therefore, if you focus upon Pleistocene mammals for part of your fossil road trip (and use specimens from a local university geology museum), please include a general environment of deposition for Pleistocene mammals in your area. What was the landscape like in the Pleistocene? You should describe at least two different geologic times for your area or two different paleoenvironmental interpretations of your area. Remember, you have a minimum of three different sites that you must visit, and from these three, you must incorporate fossil specimens. It is desirable that you choose *different* paleoenvironments for at least two of your informal sites. If you investigated a Cretaceous reef exhibit at a field site (and described your local area as underwater in a shallow Cretaceous sea), please make sure that you choose another environment and/or geologic age for at least one of your other sites. (Your Cretaceous sea may have given way locally to warm forests, and your fossil specimens may include Eocene mammals at another site or museum.) It is your choice whether you would like to describe a third local environment (geologic age and/or environment) from your third required site or whether you use one of the two described environments for the third site. (In other words, you may have

two sites—e.g., a museum and a Cretaceous reef in the field—illustrating your description of your local area under Cretaceous seas.)

(a) Summary: You will need a minimum of two different paleoenvironments. You may choose to investigate a theme such as reefs of different periods, or terrestrial, aquatic, and airborne organisms of one particular period. Just make sure that you can describe your local area—or an area within driving distance—in at least two different geologic times or two different environments.
(b) Your other quarterly projects should be *directly* implemented into this project as much as possible to save you valuable time. Your palynology MicroWorld project should have yielded some valuable paleoenvironmental information for your area, just as your ichnofossil project did.

3. *The field sites*: A general description of each of the informal educational sites you investigated is also required. If this is a public, "formal" informal site (such as a museum, fossil park, or university museum) be sure to include the number of annual visitors, the targeted age group(s), and/or outside support the facility receives. Any brochures, lesson plans, group discounts, or other pertinent information that the site offers would add to your project and may be included.

(a) You may interview an educational director at each site to obtain this information. Be sure to cite the interview in your reference list as "interview" or "direct correspondence."

(b) If you choose fossil outcrops, please provide a general description of where the site is located (e.g., roadcut along Highway 125, 2.5 miles west of New Town, exposing the Prairie Bluff Formation). GPS coordinates are also nice and can be obtained from the free Google Earth software if you don't have a GPS unit or a GPS application on your phone.

4. *The classroom application*: In *Part II* of this project, you will need to develop a mini-unit that includes activities for each informal educational site—or a combined activity utilizing the three sites (and addressing at least two paleoenvironments)—for the age group that you currently teach. These activities may be components of a larger unit (e.g., a multiple-stop field trip), or they may be stand-alone activities.

(a) Provide a brief description of your current classroom, including grade, courses taught, and whether your students possess any special needs and/or require accommodations. You may use earlier descriptions from application activities unless you are addressing a different classroom with this project.
(b) Develop activities using the three sites and two past paleoenvironments. This may include a field trip activity for your class and a hands-on activity (e.g., if you investigate a children's informal site). You do *not* have to "field test" your activities within your classroom this semester, but it is my hope that you will end up with activities that you will be able to include in your future classrooms.

(c) Be sure to include your objectives for the activity, state competencies/benchmarks/standards, and any national standards (NSES) that are addressed. (Please state the actual objective, instead of identifying objectives only by alphanumeric codes.) You must incorporate higher order thinking skills in at least one of your activities. Please specify how you accomplish this within the activity's description.
(d) You must address more than one learning style in the three activities. Please describe exactly how you accomplish this.
(e) You must provide at least one assessment tool for the activities.
(f) *If you are not a classroom teacher, please contact me for an alternative assignment to this requirement.*

5. *The submission*: Assemble your specimen photographs, descriptions, and classroom activities in a booklet or paper. Because photographs may be large files, you may need to upload your project in a series of files in order to submit it. Please use MS Word for your text; you may incorporate photographs directly into a Word file, or you may submit them separately in jpg format.

   (a) All submissions should be made directly through the myCourses Assignments tab.
   (b) If you submit your photographs separately, please label the *files* with your initials and their appropriate placement in your document (RMC Fig. 1, etc.). Please note where each figure belongs in your paper if you do not incorporate the photographs directly.
   (c) Please make sure your name is on each MS Word submission. (For example, you may choose to submit photographs and descriptions for each informal site as separate files and your classroom activities as separate files. Please type your initials in the header for each file.)
   (d) You may use any standard style for writing and assimilating your project, including—but not limited to—APA, MLA, or Chicago Style. You must consistently use the same standard writing style, however.

6. Projects are due on ________________________________.
7. A tentative rubric for the assessment of this project is included on the next page. Additionally, projects are scored with a multipage checklist that notes whether (1) three informal sites were used and described; (2) two paleoenvironmental descriptions are included; (3) the location, period, relative age, identification, description, and photograph with required scale/logo are included for each of the required 10 fossils; and (4) all classroom mini-unit requirements—objectives, class description, assessment, etc.—are present.
8. You may incorporate this research into your local field course. The time you spend developing this assignment is applicable for your local field course as well—especially if the exhibits represent the local geology of the area. (For example, you may develop an activity involving a fossil "guide" than can be downloaded from your Local Field Course website.) Several students reported

in the past that the majority of their "field work" from their 4th Qtr project was directly applicable to their local field course.

9. *Bonus points*: *Include an illustrated map of your Fossil Freeway, with your three sites identified. Check out Johnson and Troll's text for examples*.
10. Happy Hunting! If you encounter any problems or have questions during this project, please feel free to contact me.

Appendix 2: Checklist and Rubric for the Fossil Freeway Project

History of Life Fourth Quarter
Fossil Freeway Application Exercise

Student name: ___________________

Category	4 – Excellent	3 – Good	2 – Average	1 – Poor
Amount of information	All specimens are present and all information regarding the specimens is available	All specimens are present and most information regarding the specimens is available	All specimens are present and some information regarding the specimens is available	Specimens and information are missing
Quality of information	Information clearly relates to the specimen. Scientific rigor was incorporated, and several supporting details are included	Information clearly relates to the specimen. Scientific rigor was incorporated, and 1–2 supporting details are included	Information clearly relates to the specimen. Some scientific rigor was incorporated; no supporting details are included	Information does not relate to the specimen
Photographs and illustrations	Photographs and illustrations are neat, accurate, and add to the reader's understanding of the topic	Photographs and illustrations are accurate and add to the reader's understanding of the topic	Photographs and illustrations are neat and accurate and sometimes add to the reader's understanding of the topic	Photographs and illustrations are not accurate or do not add to the reader's understanding of the topic

(continued)

(continued)

Category	4 – Excellent	3 – Good	2 – Average	1 – Poor
Classroom activity	Classroom activities are appropriate, with objectives and standards clearly stated and exemplary work exhibited	Classroom activities are appropriate, with objectives and standards clearly stated	Classroom activities are appropriate, only some objectives and standards stated	Classroom activities are inappropriate
Classroom assessment	Assessment is very appropriate and exemplary with higher order thinking skills and different learning styles addressed	Assessment is appropriate with higher order thinking skills and different learning styles addressed	Assessment is appropriate with higher order thinking skills or different learning styles addressed	Assessment is inappropriate
Organization	Information is very organized with well-constructed paragraphs and subheadings	Information is organized with well-constructed paragraphs	Information is organized, but paragraphs are not well constructed	The information appears to be disorganized

Fossil Freeway Project Checklist

Fossils	
(A) Specimens	
1. Specimen 1	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____

(continued)

(continued)

2. Specimen 2	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
3. Specimen 3	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
4. Specimen 4	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
5. Specimen 5	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
6. Specimen 6	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
7. Specimen 7	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
8. Specimen 8	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
9. Specimen 9	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____

(continued)

(continued)

10. Specimen 10	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
11. Specimen 11	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
12. Specimen 12	
(a) Photograph	_____
(b) Identification	_____
(c) Distinguishing features	_____
(d) Where collected	_____
(e) Geologic age	_____
(B) Paleoenvironments	
1. Environment 1 description	_____
2. Environment 2 description	_____
(C) Exhibits	
1. Informal Site 1 description	_____
2. Informal Site 2 description	_____
3. Informal Site 3 description	_____
Part II: Mini-unit	
(A) Classroom description	_____
(B) Activities	
1. Objectives	_____
2. National standards/state benchmarks	_____
3. Higher order activities specified	_____
4. Learning styles specified	_____
5. Assessment tool	_____

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Supporting the Transition from Geoscience Student to Researcher Through Classroom Investigations Using Remotely Operable Analytical Instruments

Jeffrey G. Ryan

1 Introduction

A key juncture in the education of undergraduates in the sciences is the intellectual transition from a directed learner to a largely independent investigator. Undergraduate geology programs have historically tried to provide the kinds of integrative experiences that help students develop some of the technical and intellectual skills needed to do geoscience research as part of field-based "capstone" experiences (e.g., traditional field geologic mapping courses and "new wave" field courses on hydrology, volcanology, etc.; see Geology Field Camps/Field Courses for 80+ Schools 2012). Far less has been done in this regard in other parts of the undergraduate geoscience curriculum, though in recent years interventions have been piloted in non-capstone geoscience courses aimed at providing students practice in modeling some of the behaviors of professional geoscientists (see Lord et al. 2003; Beane 2004; Gonzales and Semken 2006; Guertin 2006; King 2006, 2007; Peterson et al. 2007; Fryar et al. 2010; Pearce et al. 2010). Many of these in-class experiences involve student use of modern research analytical and computational instrumentation, as the professional geoscience discipline has moved strongly in the direction of instrumental analysis, and many of the faculties who teach these courses are using such instrumentation in their own research. Such data as has been collected on the educational impacts of these experiences indicate that both students and their instructors enjoy such activities and students view them as empowering (e.g., Beane 2004; Guertin 2006; Pearce et al. 2010). A limitation encountered in nearly all these past efforts is one of logistics and equity: how can one engage many students in the use of what is often a single available research instrument, that is generally not located in or near the classroom, such that all students have a substantive and beneficial experience, and the exercise is itself not disruptive of other necessary course activities.

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The project discussed in this contribution, funded by the Course, Curriculum, and Laboratory Improvement (CCLI) Program in the Education and Human Resources Directorate of the US National Science Foundation, sought to examine new strategies for integrating education in research practices into introductory and upper-level geology courses by making use of remotely operable research instrumentation: specifically, the electron microprobe (EMP) and scanning electron microscope (SEM) analytical instrument systems, which can support real-time student data collection in the classroom as part of course-related research projects. Specific objectives of these interventions were to determine whether minimizing the logistical limitations associated with such experiences improved student success in science courses, and whether or not they can aid in the development of an investigative mind-set and the associated behaviors of researchers in students.

2 Background: Classroom Use of Research Instrumentation

The use of varied kinds of research instrumentation as part of classroom activities has long been a part of science instruction (see Woltemade and Blewett 2002; Lord et al. 2003; Noll 2003; Beane 2004; King 2006); for example, ACS accreditation of undergraduate chemistry curricula includes a requirement for instrumental analysis commonly met through nuclear magnetic resonance (NMR) spectrometric activities (see American Chemical Society 2012). Numerous efforts focused on instructional innovation via research instrument use in the classroom have been funded by the NSF Instrumentation for Laboratory Improvement (ILI) and Course, Curriculum, and Laboratory Improvement (CCLI) Programs over the past 15+ years (see AAAS 2004, 2008). Such evaluation results from these projects as have been reported – generally various kinds of student impression surveys – have demonstrated that students see these activities as engaging, and they feel they are building scientific skills. However, the benefits these activities have had on learning in the impacted courses or on student behaviors, choices, and/or professional directions have not been carefully examined and are more challenging to measure.

Limited student access to instrumentation has been a prime concern for those efforts involving the use of laboratory-based instrumentation in geoscience courses (Beane 2004; King 2007). While certain kinds of instrumentation (e.g., petrographic and binocular microscopes; King 2006) are routinely available in geoscience programs, access to other, more expensive tools is generally limited, if they are available at all. A key aspect in many past funded studies was the acquisition of specific big-ticket instruments for classroom use: X-ray diffractometers, plasma optical emission spectrometers, inductively coupled plasma mass spectrometers, and even scanning electron microscope systems have been purchased primarily for classroom application with NSF grant support (see CCLI and TUES Awards by State 2009). Even with such purchases, the challenges of bringing a classroom of students to an instrument that is generally (and for safety and other reasons, necessarily) housed somewhere other than the classroom, and enabling all students to participate in and benefit from the experience, continue to be a significant and at times prohibitive concern. As well, the integration of instrument use into courses raises questions about the amount of class time required for instrument training so that students can use the tools correctly and what this time "costs" in terms of the coverage of other course topics, as well as about the amount of time using the instrument that may be necessary for students to benefit from it educationally.

Intervention Strategy and Methods: To try and work around these logistical obstacles, I have pursued the alternative strategy of integrating remotely operable instrument usage into introductory- and upper-level geoscience courses. Remote instrument operation, an innovation derived from advances in modern networked information technologies, is utilized routinely by observational astronomers and planetary scientists (as examples, see Space Telescope Science Institute Portal (2012) and Holmes et al. 2011). Similar capabilities are now becoming available as a standard option for an increasing number of computer-driven analytical instrumentation systems focused on chemical analysis and micro-imaging. The specific instrumentation used here, a scanning electron microscope and an electron microprobe system, housed at the Florida Center for Analytical Electron Microscopy (FCAEM) in Miami, FL (a JEOL 8900R Superprobe with five wavelength dispersive spectrometers, an energy dispersive spectrometer, and electron backscatter and X-ray mapping capabilities; and a JEOL JSM 5900LV scanning electron microscope with an EDAX energy dispersive spectrometer; see http://www2.fiu.edu/~emlab/home.html), permits high-resolution imaging of geological samples as well as qualitative and (in the case of the microprobe) quantitative chemical analysis of individual mineral grains and other features at the 5–10 μm scale. These instruments can be fully operated at a distance through the use of widely available UNIX terminal emulation software (VNC Viewer: www.RealVNC.com) that will run on any variety of desktop or laptop computer with suitable graphics capabilities. Optimally the remote operation computer hardware should include two monitors, to better differentiate the "operations" and "imaging" windows in the software (Fig. 1), but one can run with both windows without difficulties from a laptop computer, and I often encourage students to log into the public "imaging" window to follow what we are doing on a particular sample. Internet bandwidth requirements for reliable instrument operation and use are on the order of ~10 Mbyte/s, substantially less than standard to-the-desktop and wireless bandwidth capacity in most US academic institutions (now running from 100 Mbyte/s to 1 Gbyte/s), so there are in practice no connectivity limitations on remote instrument use.

The specific classroom interventions pursued in this project involved the integration of remote microprobe and SEM data collection and interpretive activities into a junior-level mineralogy/petrology course for geology majors at the University of South Florida (GLY 3311C: the Solid Earth) and an introductory-level, variable topic natural science course (IDH 3350: Natural Science Honors), focused in my case on solar system studies, and designed for non-majors in the Honors College, both at the University of South Florida, in Tampa, FL, USA. In both cases, the instruments are parts of culminating data collection activities within term project assignments that students work on for at least half of each academic semester (Table 1). The projects

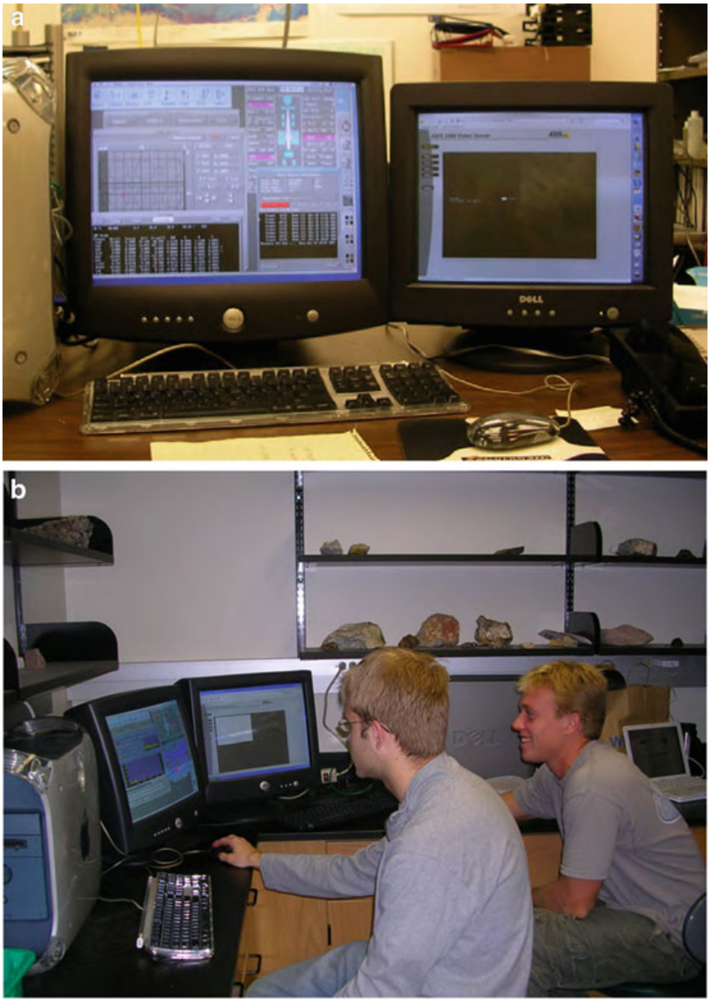

Fig. 1 (**a**) Computer interface of the electron microprobe remote operation system, using VNC viewer. (**b**) Students using the FCAEM electron microprobe during my GLY 3311C undergraduate course

are tailored to the specific courses and student audiences: in the geology majors course, students investigate suites of rock samples collected from specific sites during a required class field trip, while in the non-majors course, students characterize unknown rock and material samples, including some provided by community members, to determine if any are meteorites. In both courses, students are provided with substantive training in geological sample/material analysis, including the measurement and documentation of physical properties, preparation of thin sections, and their study using petrographic microscopy. The depth of this training varied with the

Table 1 Impacted courses and intervention strategies

Course (title): level; audience	GLY 3311C (the Solid Earth): junior/senior; geology majors	IDH 3350 (Natural Science Honors): all; non-majors
Impacted assignments	Term Project 2: Petrogenesis of central NC Blue Ridge metamorphic rocks	"Rocks" Project (identifying extraterrestrial materials from samples provide by local citizens + others from popular mineral shows, etc.)
Related student hands-on activities	Sample preparation (cutting and thin sectioning of collected rock samples); hand specimen description and mineralogy; microscopic petrography of prepared thin sections; identification of samples for microprobe study and sample polishing	Sample preparation (cutting/thin sectioning of unknown samples); textural description of hand sample; physical tests (hardness, streak, magnetism); microscopic description of thin sections
Instrument-based activities	Whole-class exercise in electron microprobe features and use (3 h); scheduled time for individual analyses (~1 h/student)	Whole-class exercise in scanning electron microscope/EDS features and use (2 h); scheduled time for individual/team analyses (~1 h/student)
Supporting interpretive activities	Lab activities: common igneous and metamorphic rocks in thin section (4 labs)	Lab activity: common minerals found in meteorites
	Exercise: translating mineral analyses to mineral formulas	Lab activity: common textures of sedimentary rocks
	Exercise: ACF and AFM diagrams and their use	Lab activity: common textures of igneous and metamorphic rocks
	Exercise: common geothermometers and geobarometers	Lab activity: common meteorites under the microscope

backgrounds of the students in each course and the sophistication of their project tasks (e.g., students in the non-majors course focused on the recognition and description of rock textures under the microscope, while those in the geology majors course received more comprehensive training in optical mineralogy and thin section petrography toward conducting mineral identifications and phase assemblage determinations). The model of instruction was that of the "studio classroom" (see Perkins 2006), in that lecture and laboratory activities were integrated, in these cases with a strong emphasis on laboratory activities. Traditional laboratory exercises in both courses, in particular those associated with petrographic microscopy and working with chemical data, were reoriented to more explicitly support student needs during their term projects. Students modeled common research practice by utilizing their thin-section petrographic studies of samples to identify suitable targets for microprobe/SEM study, both in terms of the "best samples" to examine, as well as documenting specific locations in their samples for more detailed study.

The flexibility that remote instrument operation affords allows one to easily conduct of in-class activities involving instrument use, aimed at familiarizing students with the instrumentation and providing some initial hands-on training (see Ryan 2010; http://serc.carleton.edu/NAGTWorkshops/geochemistry/activities/46409.html for an example). Each course includes a full-session, whole-class interactive laboratory exercise in which students are introduced to the instrumentation and learn about its features and various measuring and imaging capabilities through live demonstrations and the conduct of sample imaging and quantitative mineral chemistry analyses, which the students help direct – I “drive” the sample stage and toggle switches at student direction, even if those directions are mistaken and we need to backtrack. The intent of the whole-class activities is to help get students past any fears they may have in using an expensive piece of research instrumentation and to provide them with a baseline familiarity with the functioning of the instrument that helps minimize the time spent on individualized training.

Data collection using either the microprobe or SEM occurs during class time and (as requested by the students) during agreed-upon periods outside of class time. While I explain the concepts of instrument calibration and standardization for quantitative measurement during our in-class interactive session, and I lead students through choosing standards during their time on the instruments, I conduct the very time-consuming task of collecting intensity data on microprobe standard materials ahead of making any student measurements. The FCAEM microprobe is remarkably stable in terms of its signal intensities, so one can run a set of standards early in a semester and obtain reliable concentration data for unknowns based on these values for several months. I establish the schedule of possible times for instrument use, in cooperation with the FCAEM staff, using their online calendar tool.

A key strategic choice I made for managing student labor and time commitments with these instruments and the preparation of samples for them was to divide each class into several working teams, focused either on particular field sites in the geology majors course or on a particular unknown sample in the introductory course. This approach is modeled on past successful experiences in managing student researcher cohorts as part of an NSF-supported Research Experiences for Undergraduates (REU) Site project, in which we observed that undergraduates develop technical skills more quickly and are more productive as investigators when working in groups of three or more (Peterson et al. 2003). Students on each team share and coordinate the labor involved in sample preparation for petrographic microscopy and SEM/microprobe study, choose the target samples/locations on samples to examine via probe or SEM, and cooperate on conducting their analyses (Fig. 2). Chemical data and imagery from the microprobe and SEM are downloaded from the FCAEM server into the online Blackboard-based courseware site for each class, where they are available for use by everyone in the course as they see fit in the writing of their project reports. In their project reports, students are responsible for describing the sample(s) they were tasked with studying and providing a contextualized explanation and interpretation based on their observations. For geology majors, this involves delving into the relevant geologic literature of the southern US Appalachian mountains (a task that often involves physically visiting the library, as

Fig. 2 University of South Florida (USF) undergraduate student Nathan Collins (*right*) explaining his poster presentation to a visitor at the 2009 Geological Society of America Southeastern Section Meeting, one of the five students who completed independent research projects as an outcome of this effort

much of this literature predates the Internet) and contrasting their in-class results with those of past research efforts, while for the non-majors course, this task focuses on documenting the relevant characteristics of the more commonly found meteorite classes and contrasting these with the observed features and properties of their chosen rock sample.

Strategies for Data Collection on Classroom Impacts: Data on student impressions of the instrument-related activities and of the courses were compiled for the project by staff of the USF Center for Research, Evaluation, Assessment and Measurement (CREAM) using an anonymous survey instrument delivered to students online through our institutional courseware system; typically about 50 % of the students responded to these surveys. To better understand how these experiences impact student curricular choices and behavior, students were also tracked longitudinally in several specific ways:

(a) Enrollment in a permit-only one-credit research course (GLY 4947L) focused on hands-on microprobe/SEM applications, which was offered each semester and in summers during the funded duration of the project. In this course, students were expected to complete data collection for an agreed-upon analytical project that made use of either the electron microscope or the microprobe. Students completing either GLY 3311C or my IDH 3350 course section were alerted to this opportunity, which required that they receive my permit as the instructor to enroll. Many of the students requesting admission to this course wished to continue with it for more than one semester, in part because of the scale of the projects they were undertaking.

(b) Completion of an independent undergraduate research project, defined as completing their efforts to the point presenting their results at a national or regional professional geoscience meeting.

(c) For students who have either taken the GLY 4947L offering and/or completed a research project, we have attempted to track their initial post-graduation choices (i.e., attending graduate school, seeking employment, etc.)

3 Results: Student Impressions and Post-course Directions

To date four annual offerings each of GLY 3311C and IDH 3350 have involved microprobe and/or SEM use in term projects, involving ~90 geology majors and ~80 introductory science students. Three of these years included the collection of student impression data as part of the funded project. Student impression survey results compiled thus far indicate a strongly positive response to the course and to using the microprobe or SEM as part of the course (Table 2). These results are consistent with the findings of Beane (2004) related to student use of an SEM acquired for classroom-based geoscience activities and outcomes of other instrument-oriented geoscience course interventions (e.g., King 2006, 2007). One prominent difference in student responses between the non-majors and geology majors cohorts related to their inclination to take further science and geoscience courses: responses of the geology students to this question were strongly positive, while those in the non-majors offering were mixed to negative (Table 2: boldface rows). This difference may arise in part from the self-perceived academic and professional trajectories of the two cohorts: most of the students in GLY 3311C are declared geology majors and would be taking more science and geology courses in any case, while the non-majors course students were predominantly nonscience majors or enrolled in premedical programs with "wired" curricula, wherein additional coursework in geology or the sciences was not tenable, irrespective of their interest levels.

A similar and possibly externally forced dichotomy appeared in the numbers of students who chose to follow their classroom experiences with further hands-on experiences: only two IDH 3350 students have undertaken such activities in the 4 years the course has been offered, and only one of these students sought GLY 4947L course credit for the experience. However, in the GLY 3311C course, the number of participating students climbed each year, with ~25 % of those enrolled in GLY 3311C (six students) seeking permits into my GLY 4947L course by the third year of the project. While during my time on the USF geology faculty

Table 2 Student impression survey results for the two impacted courses (2008, 2009, 2010 offerings)

GLY 3311C [no. responding =41; no. geology majors: 33]	Not at all *n* (%)	Somewhat *n* (%)	Definitely *n* (%)
The use of instrumentation facilitated my learning of science	0	3 (7 %)	38 (93 %)
I have greater confidence in MY UNDERSTANDING OF SCIENCE from the research data collection and interpretation project using the electron microprobe	2 (5 %)	14 (34 %)	23 (61 %)
I have greater confidence in USING THE SCIENTIFIC KNOWLEDGE I have gained from the research data collection and interpretation project using the electron microprobe	3 (7 %)	9 (22 %)	29 (71 %)
Working in groups in the lab helped facilitate my understanding of the course materials/content	3 (7 %)	10 (24 %)	28 (69 %)
This experience has motivated me to take further science courses (not geoscience)	**5 (14 %)**	**17 (46 %)**	**15 (40 %)**
IDH 3350 (no responding =23; no. geology majors: 0)	Not at all *n* (%)	Somewhat *n* (%)	Definitely *n* (%)
The use of instrumentation facilitated my learning of science	0	0	23 (100 %)
I have greater confidence in MY UNDERSTANDING OF SCIENCE from the research data collection and interpretation project using SEM	1 (4 %)	8 (35 %)	14 (61 %)
I have greater confidence in USING THE SCIENTIFIC KNOWLEDGE I have gained from the research data collection and interpretation project using SEM	1 (4 %)	6 (26 %)	16 (70 %)
Working in groups in the lab helped facilitate my understanding of the course materials/content	0	4 (17 %)	19 (83 %)
This experience has motivated me to take further science courses (not geoscience)	**6 (26 %)**	**11 (48 %)**	**6 (26 %)**
This experience has motivated me to take further geoscience courses	**8 (35 %)**	**11 (48 %)**	**4 (17 %)**
This experience has motivated me to pursue a geoscience degree	**19 (83 %)**	**3 (13 %)**	**1 (4 %)**

member I have encouraged interested undergraduates to undertake research projects under my supervision, the average number of students doing so each year was seldom more than one or two, save during the few years that I have had dedicated grant funds to provide stipends for undergraduate participation in projects (i.e., NSF Research Experiences for Undergraduates (REU) support), when I have been able to engage as many as three students/year. That on average 2–3 times as many students are taking me up on the offer to pursue research coming out of my GLY 3311C course as in the past, and that they are willing to do so for academic credit as opposed to a stipend is a small but nonetheless interesting change in student behaviors that has taxed my time and the capacity of my research lab, albeit in a positive way.

Table 3 Undergraduate research projects developed from classroom microprobe/SEM activities

Title (date)	Problem; measurements
Genesis of Fe-Al-Si rich "pink horizons" in Buck Creek amphibolites at Glade Gap, NC (Klute and Ryan 2008)	Mineralogical and bulk chemical characterization of anomalous mineral assemblages in a well-characterized amphibolite suite; microprobe mineral identification, bulk chemical composition via plasma emission spectrometry
Testing the chemical fingerprint of amphibolites from the central Blue Ridge Cartoogechaye and Mars Hill terranes, NC Blue Ridge (DeWitt et al. 2008)	Characterization of regional suite of amphibolites; microprobe mineralogical identification
Using mineralogy and mineral chemistry to correlate mafic rock units in the southern Blue Ridge (Donovan and Ryan 2009)	Comparisons of metamorphosed mafic rock massifs and blocks within the central Blue Ridge province; petrographic and microprobe identifications of mineral suites
Petrogenesis of amphibolite blocks from the Tatham's Creek/Savannah Church area, North Carolina Blue Ridge (Collins and Ryan 2009)	Igneous origins and metamorphic history of a suite of amphibolite blocks in an olistostromal unit; petrographic and microprobe mineral identification; geothermometry and geobarometry using microprobe data
Metamorphic history and assemblages of matrix rocks in the Cullowhee olistostromal terrane (Joseph and Ryan 2010)	Protolith identification and metamorphic history of metapelitic rocks near Cullowhee, NC; petrographic and microprobe mineral identification, geothermometry and geobarometry, preliminary monazite dating

In an unanticipated event that developed following the fourth offering of the modified GLY 3311C course, a subset of the students petitioned the department to offer our senior-level undergraduate elective course in petrology (GLY 4310C) for the first time in over 10 years, modeled on the GLY 3311C experience. GLY 4310C was offered in the spring of 2011 for the 11 requesting undergraduates, focused on the field and laboratory study of intrusive and extrusive igneous rocks, respectively, in southern Nevada and southwest Virginia.

Of those students who have participated in the above follow-on courses and activities, five have thus far carried independent research projects to the point of presenting their results at sectional meetings of the Geological Society of America (Table 3; Fig. 2). These projects have varied from a relatively straightforward characterization of newly collected Blue Ridge metamorphosed mafic rocks to relatively sophisticated thermobarometric studies and even rudimentary monazite dating (Table 3), all of which are accessible analytically using the microprobe. Three of these five student presenters are pursuing M.S. or Ph.D. studies in geology, two of them at USF; overall about half of those students who participated in post-course research classes or conducted projects have sought to pursue geoscience graduate training.

4 Implications and Challenges

While the populations impacted in this study are small, some of the trends observed in student responses are nonetheless interesting. Consistent with what has been seen in other studies examining the uses of instrumentation in geoscience courses, student responses to the experience are strongly positive, as are their perceptions of greater learning (e.g., Beane 2004; King 2006, 2007; Fryar et al. 2010). If anything, student responses in this study appear to be more strongly positive than those reported for other similar kinds of efforts, perhaps because the student activities with the instrumentation more explicitly emulated research practices (i.e., all measurements were on actual unknowns, with students responsible for correct mineral identifications and defensible interpretations). However, connecting student perceptions of learning to actual measures of learning related to their instrument use experiences is challenging, partly because the only validated testing instruments available in the geosciences for assessing discipline-specific learning target only introductory-level, conceptual content (Libarkin and Anderson 2005; McConnell et al. 2006), but also because much of what students are expected to learn through these kinds of activities are observational and interpretive skills that do not translate well to standard pen-and-paper test formats. What is evident based on our surveys and our post-course tracking of students is that their expressions of increased confidence are translating into an increased interest in and willingness to undertake undergraduate research efforts and like activities. A crucial step in the transition from novice to expert in any knowledge domain is extensive "practice" – expending considerable time and effort in learning and problem-solving within that domain, which leads to the development of expert knowledge, which in the case of geology includes an understanding of complex earth processes, an extensive "library" of information about earth materials, deep-earth and earth surface phenomena such as magmatism and erosion, comfort with geospatial thinking in three dimensions, and the ability to develop conceptual and quantitative models (i.e., hypotheses) based on incomplete geological datasets (Petcovic and Libarkin 2007). While our results to this point do not document the development of greater geological expertise in students from these approaches, they do indicate a willingness among the participating students to spend additional time focused on activities that can foster the development of that expertise, which given growing concerns about student learning in a "wired" environment with numerous distractors (e.g., Glenn 2010) is a promising change.

The exceptional ease of use of modern remote operations technologies presents the potential for making real-time instrumental analysis a routine part of many science courses. There are, however, time commitments on the part of both instructor and student in terms of preparing samples for microprobe/SEM measurements and in setting up the instrumentation for ready classroom application. Determining an appropriate scale for the instrumentation experience to ensure student learning and attitudinal benefits is a key concern that still remains. The classroom applications described here involved the transformation of instructional practices throughout the term in both courses; however, less comprehensive interventions, such as the addition of one or more laboratory activities involving such instruments, are entirely plausible given the technological access and merit investigation as to whether they can provide similar student benefits.

Overview

Background and Motivation

Strategies for bringing research training activities into the classroom through course-related uses of research instrumentation present a range of logistical challenges:

– Instrument access for a large number of students presents a critical limitation.
– The time commitment involved in learning instrument use can interfere with course content delivery.
– Ensuring enough student exposure to instrument use such that the experience is beneficial in terms of developing technical and intellectual skills.

Innovation and Findings

I have sought to minimize these logistical challenges of classroom instrument use through integrating the application of remotely operable instruments (electron microprobe and scanning electron microscope) into course activities in a junior-level geology majors course and an introductory-level natural science course for non-majors in our Honors College. Findings to date include:

– Increased student interest in course materials and activities due to their hands-on instrumentation experiences.
– Geology majors showed an increased willingness to undertake and complete mentored undergraduate research projects.
– Non-majors showed no greater inclination to undertake further science courses and research experiences, an outcome that may be partly related to the constraints of their selected degree curricula.

Implications for Wider Practice

– The ease of use that remote instrument operation provides permits easy student and instructor access to cutting-edge research technologies, with a relatively modest investment in supporting equipment and low ongoing costs for periodic instrument use.
– A critical element for instructors to consider is the appropriate scale of this kind of classroom innovation, relative to the learning objectives and content coverage needs of their courses.

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Using Interactive Virtual Field Guides and Linked Data in Geoscience Teaching and Learning

Tim Stott, Kate Litherland, Patrick Carmichael, and Anne-Marie Nuttall

Abbreviations

EPSRC	Engineering and Physical Sciences Research Council
ESRC	Economic and Social Research Council
FTP	File transfer protocol
GEON	Geosciences Ontology
GOSIC	Global Observing Systems Information Center
HEP	Hydroelectric Power
LJMU	Liverpool John Moores University
NASA	National Aeronautics and Space Administration
SEM	Scanning Electron Microscope
USGS	United States Geological Survey
VFG	Virtual Field Guide
WHO	World Health Organization

1 Introduction

The benefits of teaching and learning through fieldwork have long been recognised by educators in schools and universities (e.g. Andrews et al. 2003), and the notion of supporting fieldwork with web-based and mobile technologies in the Geography, Earth and Environmental Science (GEES) disciplines (e.g. Stott 2007) has been

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gaining interest over the past decade as evidenced by conferences on ‘Supporting fieldwork using information technology’ (Maskall et al. 2007), a Higher Education Academy GEES Virtual Fieldwork Conference at University of Worcester (May 2007) and a GEES Expert Seminar at Chester University in May 2011 on Open (Web-based) Fieldwork Resources. Virtual environments and e-learning resources have been shown to help students become active rather than passive learners by appealing to their multi-sensory learning ability with interactive media (Fletcher et al. 2002, 2007).

Whilst the provision of actual fieldwork in the curriculum has remained a priority for many, Virtual Field Guides (VFGs) have allowed students to gain prior and subsequent examination of field sites (Spicer and Stratford 2001). Planning and practising field skills by using the virtual resource before a visit may mitigate against anxiety and improve students’ confidence (Rozell and Garner 2000). Students are able to familiarise themselves with the field trip more fully before going out on the day. Students appreciate the demands of working in the field environment with its time limitations and the necessity of getting it ‘right first time’, and our observations suggest that they welcome opportunities to familiarise themselves with the environment and any associated assessment tasks in advance of the actual field visit. The virtual environment also encourages reflection, allowing students to review and evaluate their experience away from the site, to process information and even link field sites or features which they have in common (Dykes 2000). In addition, VFGs allow users to make links between elements of courses, for example, by integrating images and data from laboratory analyses to help explain features and processes observed in the field (e.g. rocks in thin section, SEM images, radiometric dating).

During the foot and mouth crisis in 2001, when most field sites in the UK were inaccessible, VFGs provided an alternative means of offering students some experience of field locations. As we shall describe, VFGs can also provide some compensation when adverse weather prevents some aspects of the intended fieldwork being completed or even seen, when time restricts more thorough investigation of field sites or when students’ mobility may limit access. Whilst widening access for those with learner support needs, they can ensure that temporarily absent students do not suffer academically as a result of missing key components of a course or degree which is usually taught in the field. VFGs, when made available to a wider public, can allow school students of geosciences, or those contemplating study of the geosciences in higher education, not only to gain access to representations of different field environments but also to gain an understanding of the fieldwork approaches and techniques in which they might be engaged during future study or in professional practice.

2 Virtual Field Guides at Liverpool John Moores University

At Liverpool John Moores University (LJMU), both the Faculty of Science and Faculty of Education, Community and Leisure had experience in developing VFGs and e-learning resources, respectively, to reinforce important aspects of curriculum content. Building on the success of this work, and at the request of students for virtual field guides to be associated with more of their teaching, we developed two VFGs incorporating 360° digital panoramas, video clips and colour images:

- A VFG to support a field trip to the Ingleton Waterfalls Trail in the Yorkshire Dales in the UK, associated with a Foundation Level Natural Sciences module 'Introduction to Geosciences' and a second year undergraduate module in Outdoor and Environmental Education on 'Caving and Karst Landscapes'
- A Virtual Alps VFG based on field sites which were the focus of staff and student research and which were then used with students of Physical Geography and Geology on their 'Glacial and Fluvial Processes' module in the second year and Outdoor and Environmental Education students in their third year 'Glacial and Fluvial Processes' module

The cross-faculty, multi-course collaboration was both (1) a response to the interdisciplinary nature and appeal of the fieldwork activities and also (2) a pragmatic response in the light of our prior experience, which had taught us that developing VFGs was time-consuming and complex. By collaborating between two LJMU faculties and focusing on a field site already established through collaborative research and used by staff and students from both faculties, it was hoped that efforts could be shared and that these would benefit a greater number of students across faculties and courses.

2.1 The 'Ingleton Waterfalls Trail' Virtual Field Guide: Development and Evaluation

The Ingleton Waterfalls Trail VFG was developed over a 2-year period (2003–2005) by a team which included two teaching staff, a technician and two specialist web developers who took over the actual production: making the panorama movies, compressing the photos and video clips, making overlay map drapes, hotspots, drawing diagrams and preparing a photographic glossary. The VFG, initially only accessible to staff and students at LJMU, is now available to the public (http://www.ljmu.ac.uk/NSP/ingleton/).

Twenty-two students on the Outdoor and Environmental Education programme undertook a 5-h field visit to the Ingleton Waterfalls Trail led by two experienced academic staff and were provided with a follow-up assignment to discuss landscape interpretation and evolution of the area. At the end of the field visit when students had returned to the residential accommodation, 12 students volunteered to evaluate the VFG at the field centre. Students worked in pairs and answered 24 questions on the relevant parts of the virtual tour. Once students had worked through and answered the questions, we could be sure that they had a reasonable appreciation of the VFG features and had used it to review all of the sites they had visited earlier in the day (Fig. 1). Students were then asked to complete a questionnaire individually.

Fig. 1 Part of the Ingleton Waterfalls Trail VFG showing terrain overlay and clickable hotspots (http://www.ljmu.ac.uk/NSP/ingleton/index.htm, accessed 15 Dec 2011)

In the first part of the questionnaire, students responded to simple statements with Likert scale responses from 'Strongly Agree' through 'Neutral' to 'Strongly Disagree' (see Table 1). The same questions were sometimes repeated using different language, a deliberate design feature used to improve reliability (Oppenheim 1966).

In summary, whilst the VFG certainly seemed to help students' understanding, there was strong agreement amongst students that it was not better than the actual field trip, even given the opportunity it provided to avoid inclement weather. The majority of students felt that they had learned extra information from the virtual tour which they had not picked up during the field trip, but there was overwhelming agreement that the combination of the field trip, supported by access to the VFG, represented the best way of learning about how this particular landscape had evolved.

This picture was confirmed by the open-response part of the questionnaire, in which individual students highlighted the particular advantages and disadvantages

Table 1 Numbers of responses to Likert scale items on Ingleton Waterfalls VFG evaluation ($n = 12$)

Item	SA	A	N	D	SD
1. I felt the virtual field trip helped my understanding of how this landscape formed	7	5	–	–	–
2. I felt the virtual field trip helped me interpret the landscape better than the walk itself	–	2	1	8	1
3. I felt the walk helped me interpret the landscape better than the virtual tour afterwards	–	9	3	–	–
4. I didn't learn anything from the virtual tour which I hadn't already learned during the field trip	–	2	–	8	2
5. I think the virtual tour was largely a waste of time	–	–	–	5	7
6. I think the virtual tour is a better way of learning about how this landscape evolved than wasting a lot of the day in the field	–	–	–	6	6
7. I think the virtual tour is a more efficient way of understanding the key points about landscape evolution than spending 4–5 h in the field getting tired and wet	–	1	3	3	5
8. I think that the combination of fieldwork AND virtual tour is the best way of understanding how this landscape has evolved	10	2	–	–	–
9. I think the fieldtrip is the best way of learning about how the landscape evolved	1	7	4	–	–
10. I would like to have virtual field tours available in more of my modules	8	3	1	–	–

of actual field work and the VFG, as well as the ideal situation which was having access to both. Whilst 'coldness' and 'rain' were mentioned several times, these were clearly tolerated in order to gain 'close-up' and 'hands-on' experience, particularly where this was accompanied by 'lecturer input' and 'the ability to openly discuss with lecturers'. Whilst the VFG was visually appealing and easy to navigate, and some of the features such as photo-panoramas were identified as particularly valuable, students identified its limitations: 'you don't get a feel for the location and conditions' reported one, whilst another specifically pointed to the difficulty of representing dynamic aspects of conditions such as not 'get[ting] to witness changes such as river rise'. 'Time' emerged as an important factor, with the VFG allowing more extended inspection of localities, time to see things which had not been mentioned or observed in the field or to explore them more fully, and the ability to 'work at one's own pace' (Stott et al. 2009a, p.18).

Students on the Foundation Degree in Natural Sciences were asked to provide evaluative comments via email after using the VFG, in this case without taking part in the field visit themselves. Whilst the benefits of both field visits and access to the VFG were not therefore raised, in other respects their responses aligned with those of the Outdoor and Environmental Education students, especially with quality, the ability to explore content in depth and to work at one's own pace:

> Was very impressed with the quality of the website. As I was unable to go on the fieldtrip I was still able to do my field report and get a satisfactory mark.

Table 2 Field locations and number of students participating

	Glaciers Noir and Blanc, France	Morteratsch glacier, Switzerland	Castle Creek Glacier, British Columbia
Field visit years (July)	2003, 2004, 2005	2007	2008
Staff	T. Stott (LJMU) N. Mount (BB[a]) A. Nuttall (LJMU, 2005 only)	T. Stott (LJMU) A. Nuttall (LJMU) N. Eden (LJMU)	T. Stott (LJMU) P. Owens (UNBC[b])
No. of students	2003: 4 LJMU 2004: 4 LJMU; 1 BB 2005: 13 LJMU; 1BB	14 (LJMU)	3 LJMU 1 UNBC
Students in LJMU cohorts	75	80	80
% of LJMU cohort on field visits	2003–2004: 5 % 2005: 17 %	18 %	4 %

[a]*BB* Birkbeck College University of London
[b]University of Northern British Columbia, Canada

> I found the software easy to use and understand. It was fantastic to be able to zoom in the photos and go into detail on certain sections within the photo. The software meant I could clarify what I already thought and go over sections I was not completely clear on. The diagrams made the explanations clearer and meant I could go over the material at my own speed without continually bothering the teaching staff! Above all, I found the software a great aid which clarified the subject matter. (as previously reported by Stott et al. 2009a, p. 17).

2.2 *The 'Virtual Alps' Virtual Field Guide: Development and Evaluation*

Research on Glacial and Fluvial Processes has been conducted by Liverpool John Moores University (LJMU) staff, sometimes in collaboration with other universities, at three field sites over the past 7 years (e.g. Stott and Mount 2007; Mount and Stott 2008; Stott et al. 2008). The field sites have included:

- The Glaciers Noir and Blanc in the Ecrins National Park, SE France (in 2003, 2004, 2005)
- The Morteratsch Glacier, Bernina Alps, SE Switzerland (in 2007)
- Castle Creek Glacier, Cariboo Mountains, British Columbia (in 2008)

On each of the field visits, a small number of self-selected students have accompanied staff (Table 2). The number of students represented between 4 and 18 % of the cohorts of students who were studying related modules at LJMU.

The VFG that was developed in 2008 to support student learning about fluvioglacial environments differed in a number of significant ways from the Ingleton Waterfall Trail VFG. Whilst the former was technically advanced and offered some

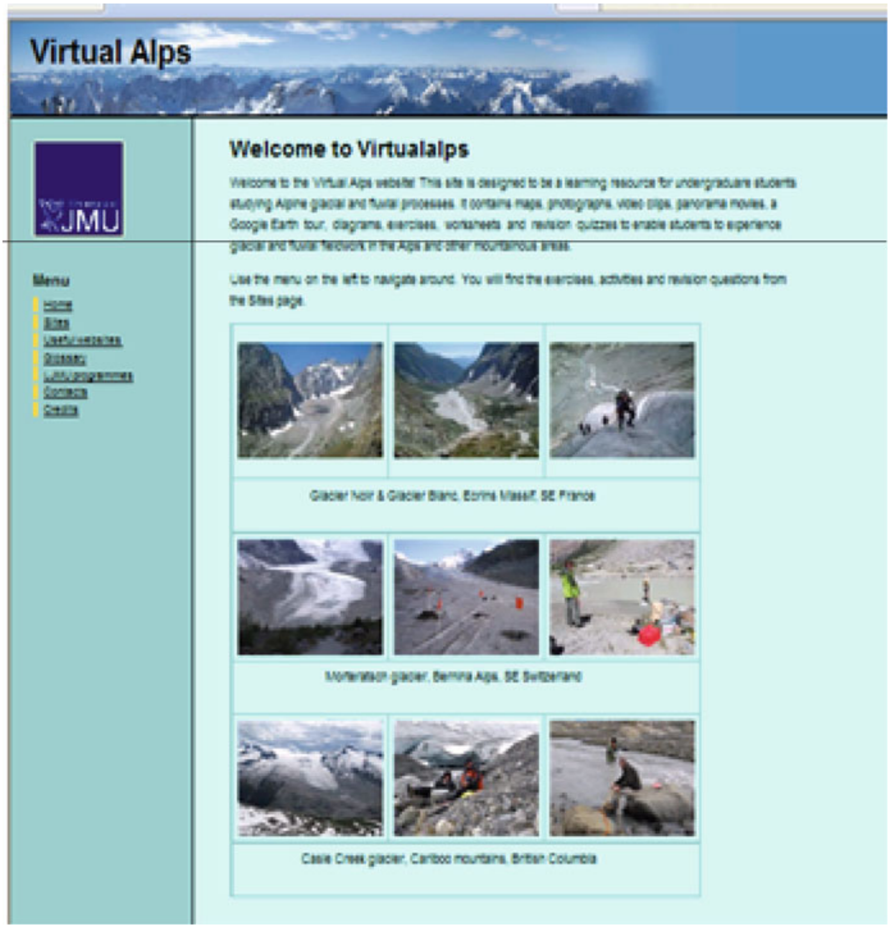

Fig. 2 The 'Virtual Alps' VFG home page (www.virtualalps.co.uk)

multimedia features to which students responded positively, the academic staff leading the project had been frustrated by their dependence on the limited availability of a specialist web developer. This new VFG, was, therefore, built using a template designed by a web specialist using Macromedia Dreamweaver, which allowed teachers to develop and update the VFG themselves, maintaining control over content and responding quickly to student comments and evaluations.

In the early stages of the design planning, the developers (Stott and Nuttall) agreed that a simple design was necessary so that our basic web authoring skills would not be too overwhelmed. Figure 2 shows the home page at http://www.virtualalps.co.uk, from which a standard 'templated' sub-site related to each location is linked.

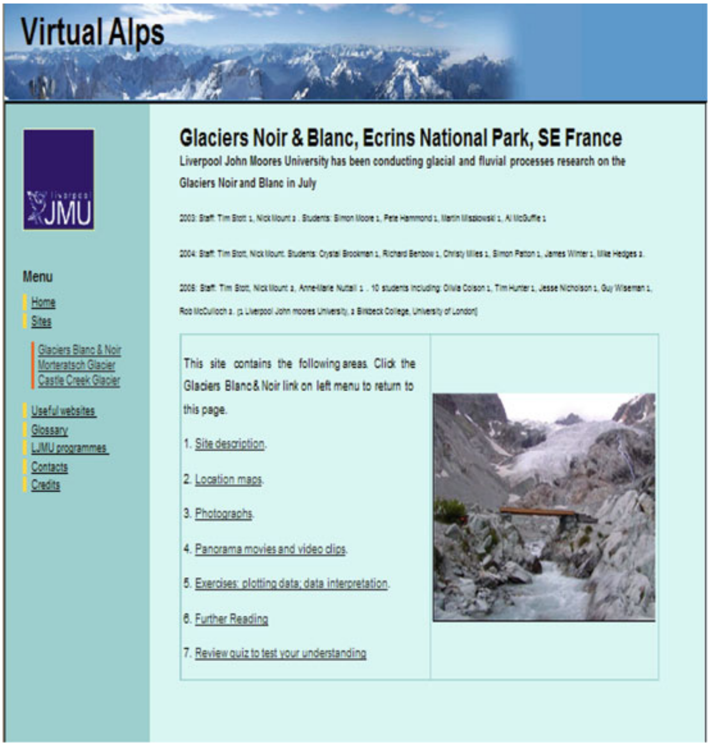

Fig. 3 One location in the 'Virtual Alps' VFG (www.virtualalps.co.uk)

- Each location sub-site has seven content areas as seen in Fig. 3. These included site description; location maps; photograph gallery; panorama movies, video clips and 'Google Earth' Tours where available; exercises (plotting data and interpretation); further reading; and a revision quiz.

Whilst teaching staff had to develop their skills in a number of areas (editing and resizing photographs, creating 'thumbnail' images and uploading content to the site using an FTP client), these tasks were not too onerous; working in templates to develop content to World Wide Web Consortium (W3C) standards allowed reasonably rapid development and, of course, left the way open for new locations to be represented in a similar format.

On completion the Virtual Alps VFG was evaluated with two groups of students: Second Year B.Sc. Physical Geography/Geology students studying 'Glacial and Fluvial Processes' in the Faculty of Science ($n = 20$) and following some minor modifications, Third Year B.Sc. Outdoor and Environmental Education students studying 'Glacial and Fluvial Processes' in the Faculty of Education, Community and Leisure ($n = 12$). The details of this evaluation have been previously reported by Stott et al. (2009b). The overall responses were generally positive about the availability of VFGs with only a small number of students agreeing or strongly agreeing with a statement that they were 'very restrictive'. The majority of students who expressed an opinion (14 of 26) expressed no opinion as to whether sites developed by professional developers (such as the Ingleton VFG) were preferable to those developed any lecturers themselves, with those that expressed a view slightly favouring lecturer-developed VFGs (7 rather than 5 who preferred those designed by web professionals). A more detailed evaluation and discussion of the Virtual Alps VFG is provided by Stott et al. (2009b).

It was against this background of student enthusiasm for VFGs, particularly to support and extend work in the field, but with some uncertainty as to whether the most appropriate, cost-effective and responsive approach was to employ specialist web developers or to up-skill teachers, that a range of new opportunities was to emerge, largely as a result of engagement in a major research project exploring the potential of a new raft of web technologies – the 'linked data' or 'Semantic' Web.

The 'Ensemble' project (http://www.ensemble.ac.uk) is a UK-based research project funded by the Economic and Social Research Council (ESRC) and the Engineering and Physical Sciences Research Council (EPSRC) as part of its Technology-Enhanced Learning Research Programme (http://www.tlrp.org/tel). The project was launched in 2008 with the intention to explore how new web technologies could support and enhance various forms of 'case-based' learning (where cases might be narratives, problems, locations, performances or 'instances') where:

> … learning environments in which the subject matter is complex, controversial or rapidly changing, and in which multiple perspectives and interpretations need to be understood. The affordances of the 'semantic web' provide a conceptual and technological basis for the development of flexible tools and associated pedagogies in which knowledge is developed, represented, adapted and then transferred. While semantic web technologies are revolutionising long-term preservation and enabling the retrieval of data from large and heterogeneous information sources, they have not, to date, been mobilised in advanced education settings that employ case based learning in support of higher order learning.

Ensemble is an interdisciplinary research *and* development project and has been involved not only in exploring and developing pedagogical practice but also technological tools and environments that might be used across a range of disciplinary settings, from pure and applied sciences to performing arts. Geosciences at LJMU was one of these settings, and teaching and project staff were able to work together to further explore what affordances the linked data and semantic web technologies might bring in the context of Virtual Field Guides. Part of this work involved assessing the current state of development of these new web technologies in the geosciences (both generally and in relation to teaching and learning) and how these might relate to prior work on VFGs such as the Ingleton and Virtual Alps examples.

3 Background to Developing Virtual Alps 2.0: Embracing Semantic web Technologies

On reading popular accounts of the development of Internet technologies, and the World Wide Web in particular over the past decade, it would appear that the main developments are aspects of mobility (the development of handheld devices), convergence (with the distinctions between conventional media like radio, television and film, and Internet technologies becoming blurred) and the rise of social networking or 'Web 2.0'. These developments have, of course, been very important, and the rise of the 'social web' (person-to-person networks such as Facebook; micro-blogging systems like Twitter; picture and video sharing through Flickr, Picasa and YouTube; and many other examples) has indisputably changed many people's experience and expectations of web technologies. But there has also been a longer-term, less well-known trend over the past decade: the move towards 'linked data' and the development of a new 'semantic web' based on interoperability, exchange and 'machine-readable' data.

The semantic web was described in 2001 in terms of the seamless integration of Internet services, in order to provide personalised user experience (Berners-Lee et al. 2001). At the heart of this vision was the idea that if *meaning* could be attached, or derived from the content of the text, images, data and other content of the Web, then, once these were linked with consistent taxonomies and technical ontologies, it should become possible for software programmes (what Berners-Lee and his collaborators called 'agents' in their 2001 article) to reason, much as a very well-informed human might do, across the whole of the World Wide Web. Effectively, a form of artificial intelligence would be possible, but with all of the diverse, distributed and heterogeneous resources of the Internet at its disposal. Such developments would clearly have enormous implications in education, both in the organisation and administration of educational systems and in the nature of the learning environments that might emerge, and the new forms of learning and interaction that might be possible within them (Koper 2004; Stutt and Motta 2004; Lytras and Naeve 2006).

However, as Shadbolt et al. (2006) and Heath et al. (2006) reported, the technological developments necessary to realise this ambition have progressed rather unevenly, with specific semantic web technologies being developed and adopted rather than the wholesale re-engineering of the World Wide Web envisaged in earlier writing. The enthusiasm with which the person-to-person networking enabled by Web 2.0 environments has meant, for example, that data linking and machine-based reasoning has been taken up in order to identify emerging social networks, enables recommender systems and supports collaborative annotation of things like personal photo galleries: what Mika (2005, 2007) has described as a hybrid 'Social semantic web'. Another key development was the articulation of a less ambitious version of the broader semantic web which has come to be called the 'linked web of data' (Bizer et al. 2009). This places less importance on the presence of established ontologies that represent expert, authoritative knowledge or categorisation systems, or reliance on rule-based machine reasoning. Instead, it is a pragmatic reflection of the fact that the starting point for many users is the data that they themselves generate, or with which they wish to engage, so the emphasis is on publishing data in common formats, accompanied by rich descriptive metadata that supports their discovery and reuse. semantic web technologies are clearly very valuable in accessing, selecting, converting, aggregating and visualising these data, without the necessity for users to fully subscribe to the more demanding programme of the 'semantic web' as a whole. These developments offered potential for a new leap forward in VFG development, and we began to look towards developing Virtual Alps version 2.0.

The idea of developing a linked web of data has also been driven by a shift towards the online publication of data by international, government, quasi-governmental and other public-funded bodies. Organisations such as the National Aeronautics and Space Administration (NASA) and the US Geological Survey (USGS) in the USA, or the Meteorological Office in the UK have a long history of publishing data via the Internet as part of their public-service role, and international agencies such as the World Health Organization (WHO) have recognised the importance of publishing data sets to enable international comparisons, longitudinal studies and impact evaluations. In the UK and USA, government departments have begun to publish reference data sets alongside the summary reports which had previously been the primary means by which the public were able to engage with government data (Alani et al. 2007). The data 'portals' at http://data.gov.uk (in the UK) and http://data.gov (in the USA) contain a wide array of data ranging from full records of government spending to very specific and sometimes obscure outcomes of "Freedom of Information" requests from individuals (see Ding et al. 2010 but also Robinson et al. 2009, on the limits to 'openness') which could be utilised in VFGs.

At the same time, sharing of research data, particularly that collected in public-funded projects, has become more common, and here linked web of data initiatives have overlapped with other data-sharing initiatives such as the "Access Grid" (http://www.accessgrid.org), a high-bandwidth network linking 'nodes' at universities and other research institutions and designed to enable collaborative analysis of the often vast data streams that emerge from experimental work in high-energy physics or gene science, or from large-scale observational work in astrophysics or climate science. The emerging combinations of new infrastructures (and, for that matter, new forms of data); standards, techniques and interfaces for sharing data; and semantic web technologies have changed the 'terrain' of some disciplines significantly. These changes, in turn, are redefining the skills and competences required in these fields and have the potential to impact the teaching and learning environments that prepare students for future roles as professionals and academics. Integrating linked web of data initiatives into a new VFG offered us the possibility of teaching our students how to develop and enhance their familiarity and ability to manage the linked web of data. We felt this would be a noble aim and would potentially enhance their skill set and widen their future prospects for employment.

Figure 4 represents the linked data that was available in 2007 to contribute to the construction of DBpedia (http://dbpedia.org), a project which was set up to extract structured information from the user-generated (and hence highly variably structured)

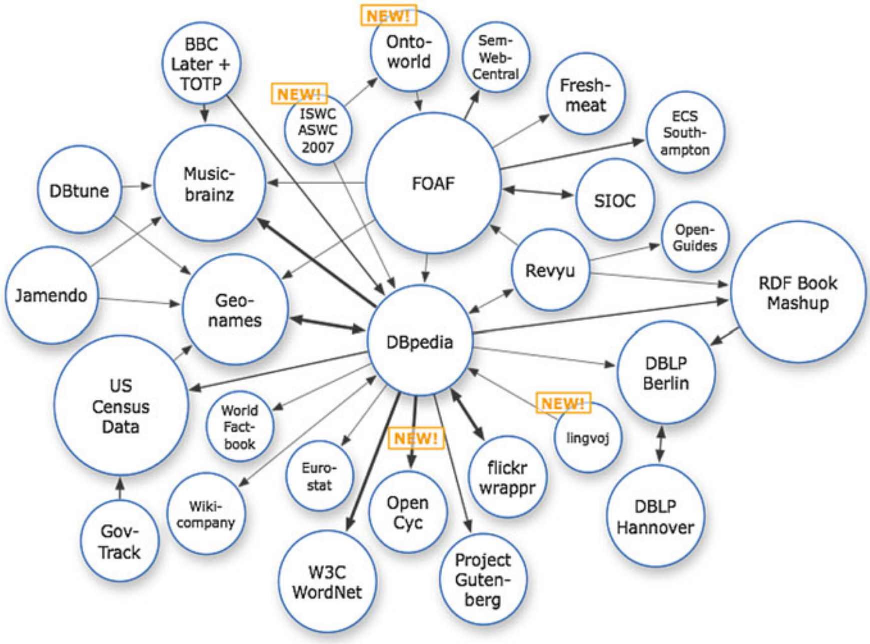

Fig. 4 The Cyganiak-Jentzsch linking open data cloud diagram, November 2007 (http://richard.cyganiak.de/2007/10/lod/lod-datasets_2007-11-07.png, accessed 15 Dec 2011)

Wikipedia and to act as a 'nucleus' for the linked web of data (Auer et al. 2007). Well-established providers such as the US Geological Survey and 'Project Gutenberg' (http://www.gutenberg.org) are present in this early map, alongside music sharing websites and some of the large-scale taxonomies, thesauri and ontologies that had been informed by broader semantic web activities. Subsequent development of this map has been undertaken by Richard Cyganiak (DERI, NUI Galway) and Anja Jentzsch (Freie Universität Berlin), and the reader is encouraged to visit the site at (http://lod-cloud.net/) where clickable copyright free versions from 2007 to the present are available, providing an illuminating insight into the growth of the linked web of data as whole as well as into the data-publishing and sharing practices of widely varying communities, disciplines and organisations.

With the establishment of the 'Data Hub' (http://thedatahub.org/), a site at which linked data providers could register their collections and the means by which they could be accessed, the map was to expand rapidly (see Fig. 5). Other centres for linked data such as FreeBase (http://www.freebase.com/), which also provided tools to support data conversion, 'cleaning' and aggregation, also played a role in enabling a broadening of the linked data community – both contributors and users – and appear as areas of higher 'density' in the map.

By the time of writing (October 2011), the Cyganiak-Jentzsch map had expanded still further (Fig. 6), reflecting additional government, research and commercial

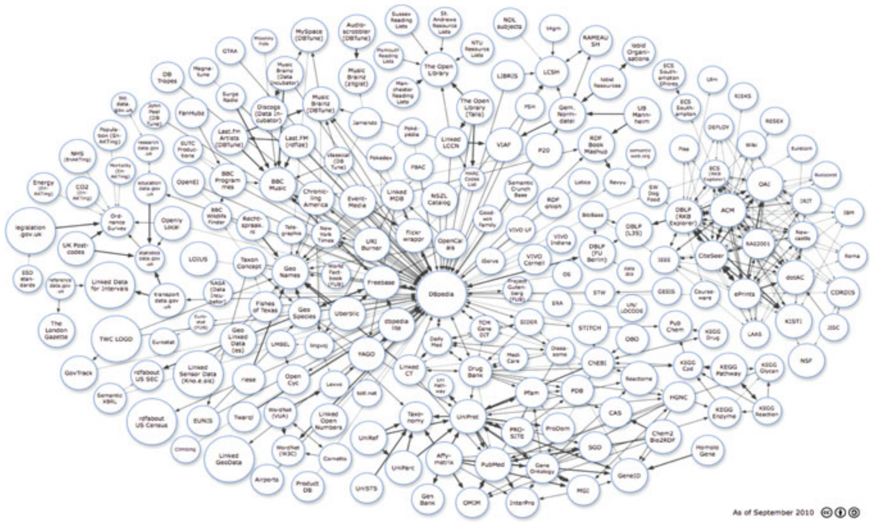

Fig. 5 The Cyganiak-Jentzsch linking open data cloud diagram, September 2010 (http://richard.cyganiak.de/2007/10/lod/lod-datasets_2010-09-22.png, accessed 15 Dec 2011)

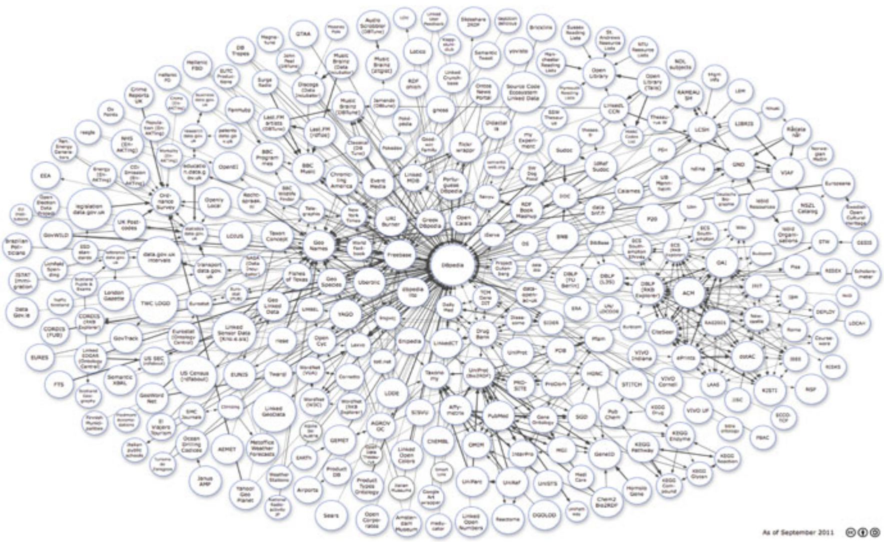

Fig. 6 The Cyganiak-Jentzsch linking open data cloud diagram, September 2011 (http://richard.cyganiak.de/2007/10/lod/lod-datasets_2011-09-19.png, accessed 15 Dec 2011)

services publishing linked data; smaller organisations such as museums and archives offering specialised collections; and updates to social networking and other websites which now allowed the collection of user comments, reviews, music playlists, photographs and annotations and other user-generated content.

Whilst the picture that emerges from this mapping exercise is one of rapid 'enrolment' of organisations and their data into the linked web of data, the density of the nodes and links on the map belies the fact that coverage is still patchy, with some jurisdictions, geographical areas or disciplinary areas, for example, far better represented than others.

4 Linked Data in the Geosciences and Virtual Field Guides

The Ensemble project's work in the geosciences at LJMU took place, then, against a background of existing VFG development and the growth of the linked web of data. A first task for the project was to explore which elements of this web of data (much of which was oriented towards communication between academic researchers) were, in addition, relevant to teaching and learning in the kinds of courses where VFGs had already been implemented. What emerged from this exploration was the same kind of 'patchy' development that, as we have seen, characterises much of the linked web of data: with a combination of 'high-level' initiatives to enable international research communication; developments to support more detailed and situated research collaborations; and a range of community and user-generated content. Significant elements of the 'map' of linked data in the geosciences include the following (with the proviso that as these are resources that the project team evaluated for the potential to support VFG development, this list is far from exclusive and will doubtless change over time).

4.1 'Portals', Offering Data, Visualisation Tools and Other Resources

Whilst several of these predate the idea of the linked web of data and use older technologies, these represent significant data repositories and are progressively making their data available in formats that allow their incorporation in linked data applications. The *US Geological Survey* provides historical and current data, analysis and visualisation tools. As well as US-specific data, it also provides data with global coverage; at one level, it allows teachers or students to import and display USGS data on popular platforms such as 'Google Maps' or 'Google Earth'; at the other, it can be used to populate very specialised research applications. The Canadian *Geoscience Data Repository* is a good example of a regional portal: as well as geospatial datasets, imagery and maps, it also provides tools such as a lexicon of periods and lithographic units and another of place names and regions.

The *Global Observing Systems Information Center* (*GOSIC*) is a portal to other providers of data not only about terrestrial systems but also oceanic ones and global climate data, acting as a 'nucleus' for data sharing and exchange in the way highlighted by the DBpedia project. The value of such sites is that they highlight areas of similarity and difference across disciplines and sub-disciplines, as well as regional differences. The *Pangaea Data Publisher for Earth and Environmental Science* (http://www.pangaea.de/), hosted at the University of Bremen and the Wegener Institute, Bremerhaven, is described as 'an Open Access library aimed at archiving, publishing and distributing georeferenced data from earth system research' and provides a means by which organisations, projects or individuals can publish data sets – either in support of publications or to enable sharing and reuse. Perhaps further advanced than other such portals in implementing linked data approaches, all data at Pangaea are shared under a Creative Commons licence. This allows reuse on the condition that the publishers are cited, and the Pangaea archive allows permanent identifiers (such as 'DOI' references) to be attached to any data set.

4.2 Taxonomies, Thesauri and Ontologies

Complementing and aiding in the structuring of the data in portals like Pangaea, GOSIC and the Geoscience Data Repository are projects which, in whole, or in part, are concerned with developing the linking systems of terms and concepts which allow data from different sources. The *GEON Geosciences Ontology* has been developed by the US-based and international GEON project (http://www.geongrid.org/), which aims to develop an infrastructure for the integration and visualisation of 3D and 4D earth science data. One of the central elements of this infrastructure is an ontology of terms designed to allow high-level communication between sub-disciplinary groupings, projects and individuals, and in particular allowing collaboration between geoscientists and information/computer scientists (Ribes and Bowker 2008). The *Geonames Ontology* (http://www.geonames.org/) fulfils a rather different role, having been developed to support more general applications beyond the geosciences, and as such it is more widely used in describing specific localities, rather than offering a detailed scientific categorisation. However, it provides a useful means of extending basic geospatial data records. It is also well-integrated with other elements of the linked web of data, allowing users (and the applications they develop) to draw on resources such as Wikipedia, Google Web services and gazetteers of place names in order to allow the identification of the 'political unit' or 'nearest population centre' to a given location. The *OneGeology* initiative (http://www.onegeology.org/) is another collaborative research network that aims to enable sharing of data across international projects and national geological survey organisations. It has implemented Geoscience Markup Language (GeoSciML) as part of the underpinning infrastructure to support this (Laxton et al. 2010). This has, in turn, provided a basis for the development of more detailed taxonomies and ontologies that complement and extend the higher-level work of GEON and Geonames, offering, for example, consistent means of describing phenomena in fluvial geomorphology, glaciology and different subdivisions of petrology.

4.3 Academic, Community and Personal Resources

The developments listed represent contributions to the kinds of infrastructures needed to implement a fully linked web of data for the geosciences. It is important, however, not to forget that there exist, in addition, substantial web resources which operate along other lines. Highly relevant to the development of the Virtual Alps VFG described above, for example, is the very comprehensive and authoritative 'Glaciers Online' website (http://www.swisseduc.ch/glaciers/). This includes large numbers of images, video clips and other resources relating both to specific locations and to themes such as glacier retreat and also contains an illustrated glossary. This is, however, a commercial enterprise and its content, much of which is associated with textbooks, is protected by copyright. The best that can be done by the developers of VFGs or other applications is to direct students to the website as a whole, or to sections or individual resources within it where they are identifiable by a unique web address.

Finally, as with other parts of the emerging linked web of data, there are many examples of data sets and other collections online and potentially available for linking, aggregation and reuse, but not, as yet, published through a central 'clearing house' or portal like 'Pangaea'. These include sets of remote sensing and GIS data, geotagged images, videos and observations, and summary data representing different approaches to analysis. These are typically made available through project or personal websites; by local climate, ocean or terrestrial observation stations; or published to Web 2.0 communities such as photo or video sharing sites (YouTube, Picasa or Flickr). Whilst these data may be easy to integrate into linked data applications or VFGs, they characteristically lack both the detailed metadata that would accompany data from one of the major projects listed above (e.g. images being tagged with locational data and text descriptions) and the authority that accompanies data provided and 'quality assured' by major research or public-service providers.

5 The Development of a New Virtual Field Guide Through Ensemble

When teaching staff at LJMU and members of the Ensemble project reviewed the elements of this emerging infrastructure (as reviewed in the last three subsections) in order to explore how they might be used to populate, extend or enhance VFGs, several issues arose. The first of these was what role would be played by each of the kinds of resources, collections and 'organising devices' (like taxonomies and tagging systems) in any future VFGs that we might develop. VFGs (also see Litherland and Stott 2012) by their nature tend to be concerned with specific locations and often employ either a visual landscape or map, a narrative of a journey in order to offer a 'way in' to more detailed engagement with images, videos, texts or data sets. At the same time, learners are encouraged to locate VFG content in broader contexts: spatial, temporal and thematic, either through the nature of the tasks set or, as in the Virtual Alps example, by presenting similar features from widely separated geographical locations. This meant that a combination of the broad, high-level frameworks such as the GEON and Geonames ontologies *and* representations of localised, situated knowledge was required: the challenge was to identify the best combinations.

The second, related issue, was to ascertain whether the main value of linked data developments was the availability of images and video to illustrate or 'populate' a VFG from diverse sources; the availability of data sets to which the VFG might link; or the provision of standardised descriptive languages allowing students to locate the content of the specific VFG with which they were working against a broader background. In the case of the Ingleton Waterfalls Trail VFG, for example, would an enhanced 'linked data' version draw in additional images or videos to enhance the visual representation of the on-screen landscape; allow students to 'click through' to linked datasets (stratigraphical columns; erosion, river flow or sediment transport data; climatic data combined with river stage records); or relate the local and situated terminology to other similar features in other karst landscapes by using a linking taxonomy or glossary? All of these (and combinations thereof) would be possible; the key, of course, was to consider the specific pedagogical purposes of the VFG, and the way in which these could be enhanced, rather than the technological artefact of the VFG itself.

Another point that emerged as a result of reviewing not only linked data sources but also existing VFGs (see Litherland and Stott 2012) was that virtually none of the latter offered data in such as way that it could in turn be linked (or linked 'back') into a broader web. VFGs were, for the most part, 'end points': presentations of selected data with specific audiences and pedagogical purposes in mind that neither *drew on* the data available through the Linked Web or Data nor were they constructed in such a way as to *contribute* to it. This raised more challenging questions: was there an opportunity to rethink the notion of the VFG not simply as a presentation of data, (linked or otherwise) but instead to see it as a 'node' on a linked web of data, not only a point of aggregation and structuring for pedagogical purposes? Could VFGs, therefore, act as *providers* of linked data for reuse and reworking by others, with teaching resources being shared, not only with other teachers but also returned to the research community as a particular kind of 'enactment' of the data they had originally provided?

6 Putting Linked Data to Work: Designing Virtual Alps Version 2.0

In the light of these questions and issues, the decision was made to redevelop the 'Virtual Alps' VFG, drawing on linked, open data that were available whilst restructuring the existing content in line with linked web of data standards and approaches. This included generating metadata records for each of the items (so that, for example, the content of images was described in a metadata record rather in the web page in which the image happened currently to be displayed). It also involved restructuring the glossary that already existed as part of the VFG so that it could be mapped against other, published taxonomies, as well as being used as the basis of keywords attached to each image, video clip or data set in the Virtual Alps collection.

At this first stage, no additional content was included: the purpose was to remodel the data contained within it and organise the existing hierarchical structure of web pages and narrative accounts into a flexible collection of data and metadata that could then be viewed in different ways and to enable its integration with some of the technologies and resources described above. This may seem like an additional level of complexity, particularly for novice web developers, but once the content of the VFG had been so adapted, it was then very easy to develop a range of quick prototypes using software designed to sit 'on top' of structured data: specifically the 'Exhibit' web application framework developed at the Massachusetts Institute of Technology as part of the SIMILE project (http://simile.mit.edu) (Huynh et al. 2007), and under further development by a community including the Ensemble project.

6.1 Exhibit

Exhibit is designed to allow the visualisation of collections of data, potentially from diverse sources and in different formats, as lists, photo galleries, on maps and timelines and charts, without the need for advanced programming or even web page writing skills. It aligns well with the ideas behind the linked web of data as, whilst there is nothing to stop taxonomies and ontologies being incorporated (to provide navigation, key wording or search functions), it will also work 'ontology-free', or rather, driven by the structure of the *data* it displays. In this respect, it had the potential to introduce new functionality into VFGs whilst continuing the trajectory from needing expert designers to develop VFGs to them being within the capabilities of the competent web author. That said, the fact that the entire Exhibit code is written in JavaScript and is released 'open source' (http://code.google.com/p/simile-widgets/) means that it can act as a component or starting point for very sophisticated web applications. For now, our interest was in what it could offer 'as-is' to the builders of VFGs.

The flexible, modular nature of Exhibit (which allows the combination of search 'facets', viewers, visualisations and other webpage content) not only opened up questions about how research data, publications and content might be reorganised within a VFG but also highlighted again the importance both of mediating teacher narratives and the centrality of the 'landscape' or 'locality'. A series of design and rapid prototyping exercises highlighted the fact that, even when the substantive tasks which the VFG was intended to address were largely concerned with data analysis (in this case, related to sediment transport), maps and images were important in developing a contextualising narrative with which students could engage. For students still learning the practices of elementary geoscience research, the landscape or locality remains the fundamental initial point of reference, even if the teacher's emphases and intentions lie elsewhere.

What emerged from these design and development activities represented an attempt to provide students with something that was sufficiently familiar that they could easily engage with it, but at the same time addressed the teacher's intention that students develop skills in manipulating, analysing and interpreting diverse data (e.g. images, Excel files, video clips), rather than simply further building confidence in procedural tasks. Associations between the different types of data were suggested by the designers, with the intention that students would be able to use the 'faceted browsing' and visualisation tools to explore these links. In this way, the narrative provided by the tutor would still be inherent in the construction of the site, but was no longer as evident or explicit. A linear, procedural narrative was replaced by an environment in which students could select data and other resources, tentatively developing narratives and avenues of enquiry whilst temporarily excluding others.

Further development work involved introducing additional resources from a variety of sources including providers of linked data, with standardised taxonomies allowing these to be related to existing content. A local 'web' of resources (what Stutt and Motta (2004) describe as a 'knowledge neighbourhood') began to emerge as a locus for student enquiry as they first familiarised themselves with the locality and the available data, and then undertook teacher-directed tasks. The 'Virtual Alps Version 2' VFG is shown in Fig. 7: the 'locating' aerial photograph accompanies an open-ended task (the teacher narrative) in which students are asked to consider the best location for a dam, reservoir and Hydroelectric Power (HEP) plant and the consequences of its construction. The data, images, video and published papers that have potential relevance to this task are then presented with some structure and direction (with links suggesting 'these resources may be useful in deciding…'), and students are able to view these and decide whether to incorporate them into their solution to the problem task.

What is immediately evident here is the change in the nature of the assessment task that was enabled by rethinking the structure of the VFG and the inclusion of linked data. Rather than the VFG being presented as a mimetic representation of the locality, the associated assessment task was now transformed from a procedural one based on a predetermined set of data, the locality, data and task are now co-located

Fig. 7 Virtual Alps Version 2 – the hydroelectric power task and linked resources (http://www.ensemble.ac.uk/projects/settings/outdoor/HEP/index.html, accessed 1 Oct 2011)

within a ‘neighbourhood’ through which students are guided by the teachers’ construction of the task, with hints and signposts being provided by the assertion of links between sections of the HEP task and the linked data resources. But there is a more far-reaching change here as well, which represents a more significant shift in thinking about the online environments with which students are provided.

6.2 Research Practice and Pedagogy in Geosciences

There is a tension and 'gap' between research practice and pedagogical practice in geosciences – as there are in many subjects – and around the content, structure and role of VFGs, which were already evident in the evaluations of the Ingleton Waterfalls Trail and Virtual Alps VFGs and in debates about VFGs more generally. Whilst there has been a general acceptance of technological developments in geosciences *research*, the *pedagogical* discussion around technological innovation in the classroom has tended to become entangled in the issue of whether or not Virtual Fieldwork should be intended as a replacement for 'real' field trips, or as to whether a virtual guide functions as useful support for students needing to build skills and confidence prior to a 'real' field trip.

Reframing the VFG so that, rather than being a 'micro world' (Papert 1980; Senge 1990) primarily concerned with reproducing a real visit to the field, it becomes, when enabled with linked data, a bridging artifice, not only to the real locality but to broader disciplinary practices and discourses in data collection, interpretation, analysis and publication. Virtual Alps 2.0 is, therefore, both a response to the pedagogical opportunities offered by the linked web of data, showing how teachers can rethink the role of web technologies in moving from linear and directive tasks, towards those which are more authentic and cognitively challenging *and* reflection of how the geosciences more generally are being transformed by the availability of new technologies and new kinds of data. This bridging takes two forms: firstly, the 'links' enabled by the linked web of data, and in this case, by the *Exhibit* web application framework, and second, by the provision of tasks such as the "Hydroelectric Power Plant" example, towards learning activities more closely emulating the decision making and critical skills required by a 'real-world' geoscientist.

This more expansive notion of 'bridging' from the specific locality to the broader practices of an increasingly technologically enhanced geoscience is reflected in a second part of the Virtual Alps Version 2.0 VFG (Fig. 8).

This does not present any teacher-directed tasks and is oriented instead towards supporting independent student enquiries, such as might be undertaken as part of a dissertation project. Maps, images, linked data and other resources are all still present and are accessed through facets and views as before, but the 'location', significantly, becomes one of the parameters by which the user can search. The subject specific taxonomies and ontologies of the geosciences are more evident here as they, rather than a teacher narrative, provide the conceptual 'framing' of much of the content. It is the learners, as they hypothesise and generate questions for investigation, who generate the narratives of enquiry, with the VFG and the data to which it links a resource on which they can draw.

If this is a 'micro' representation of anything, it is of a portal such as 'Pangaea' or 'OneGeology' rather than of a specific location. But this does not negate or reduce the role of the teacher, their knowledge of localities or the personal research data on which (as in this case) this 'linked VFG' is based. Linking data generated

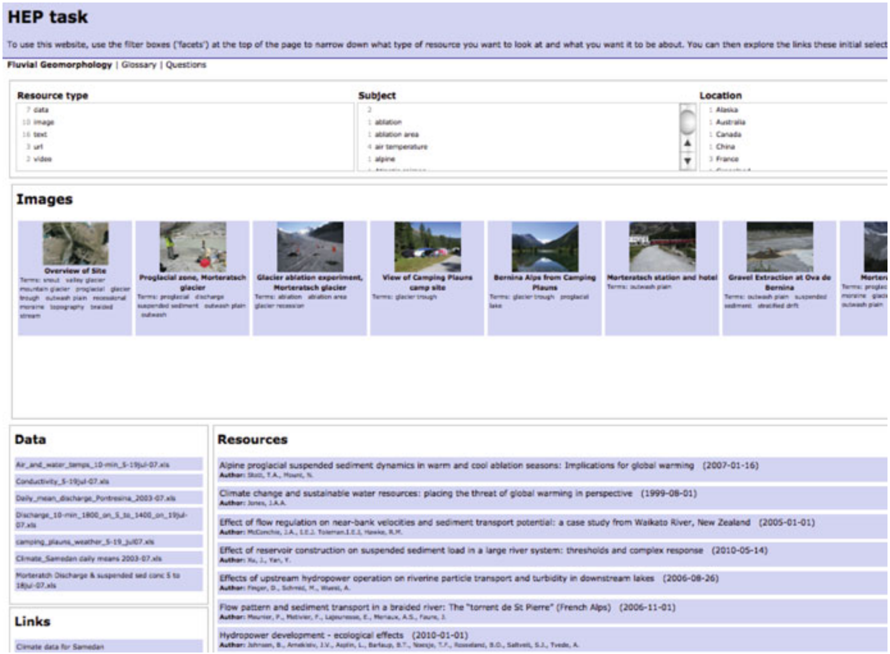

Fig. 8 Virtual Alps as a linked data portal (http://www.ensemble.ac.uk/projects/settings/outdoor/HEP/index.html, accessed 1 Oct 2011)

by teacher-researchers (and student-researchers, for that matter) to a wider network of data and offering it to students with the help of supportive framing (initially visualisations, narratives and activities), and subsequently enabling students to develop their own enquiries can be seen as a way of making a wholly new type of VFG which reflects changes in the nature of geosciences themselves. And the role of such VFGs represents a move from a curriculum based around representation and reproduction to one that supports authentic, current practices amongst researchers and professionals in the geosciences.

7 Conclusions

We have presented here an account of a process that has brought together two groups interested in supporting and enhancing teaching and learning, and specifically linking research to teaching and learning, in undergraduate geosciences. In doing so, we believe that we have uncovered some important opportunities for existing work on VFGs to be extended by drawing on emerging web technologies, resources, standards and approaches.

The ‘trajectory’ of VFG development at LJMU has taken us from the construction of a complex, visually appealing and self-contained ‘micro world’ (Ingleton

Waterfalls) through teacher-generated and easily edited locality studies compatible with web standards (Virtual Alps Version 1) to a prototype linked data application (which could also form the basis of a linked data *provider*) in Virtual Alps Version 2. The user interface of Virtual Alps Version 2 is still in a developmental phase, with teachers and students involved in continuing participatory design and evaluation activities during 2011–2012. What prior experience has shown, both in the earlier VFG projects and in the work of the Ensemble project more generally, is that students are able to perceive functionality even where style is lacking, tolerating a lack of polish where usefulness and relevance is evident, and even being more willing to participate in a design and refinement process where an application lacks the gloss of a finished product. Even if one subscribes to the notion advanced by Prensky (2001) that students are 'digital natives', this does not mean that all learning resources need to have the appearance of commercial video games or expensively maintained websites: most students are sufficiently familiar with a range of web technologies that they are able to recognise both the affordances of teacher input into learning resources and of those resources that prepare them for future employment or study. Again, the emphasis here is less on *representation* than on *practice*: not just the practices of fieldwork, but research practices associated with the generation, sharing and analysis of diverse data, and the pedagogical practices of teachers and learners in the geosciences.

The rapid evolution of the linked web of data, the incorporation of linked data approaches and semantic web technologies into many data providers in the geosciences, and the emergence of easy-to-use authoring tools means that there are exciting opportunities for the Virtual Field Guides of the future to draw on the 'best of both worlds'. Understanding VFGs as structured elements in an expansive and expanding network will enable teachers and students both to engage in depth with the practices and discourses that are relevant to a locality or specific problem whilst also locating their learning in the broader 'map' of evolving geoscience research.

Overview

Background and Motivation

- The benefits of teaching and learning through fieldwork have long been recognised by educators in schools and universities.
- The notion of supporting fieldwork with web-based and mobile technologies in the Geography, Earth and Environmental Science (GEES) disciplines has been gaining interest over the past decade.
- Virtual Field Guides developed at Liverpool John Moores University have allowed students to gain prior and subsequent examination of field sites, to plan and practice field skills and to revisit sites later to consolidate field-based learning.

(continued)

(continued)

Innovations and Findings

– At Liverpool John Moores University, a VFG was developed to support a cross-faculty field trip to the Ingleton Waterfalls Trail in the Yorkshire Dales in the UK, associated with a Foundation Level Natural Sciences module ‘Introduction to Geosciences’ and a second year undergraduate module in Outdoor and Environmental Education on ‘Caving and Karst Landscapes’. In this case a technical web developer carried out all the web authoring, directed by two academic staff.
– Next a Virtual Alps VFG was developed by two academics using no specialist technical web authoring skills or technicians based on field sites which were the focus of staff and student research.
– The increase in availability of ‘linked data in the GeoSciences’ has recently given rise to the development, in collaboration with the Ensemble project, of Virtual Alps version 2.0 drawing on linked, open data that were available but also restructuring the existing content in line with linked web of data standards and approaches.

Implications for Wider Practice

– The rapid evolution of the linked web of data, the incorporation of linked data approaches and semantic web technologies into many data providers in the geosciences, and the emergence of easy-to-use authoring tools means that there are exciting opportunities for the VFGs of the future to draw on the ‘best of both worlds’.
– Understanding VFGs as structured elements in an expansive and expanding network will enable teachers and students both to engage in depth with the practices and discourses that are relevant to a locality or specific problem whilst also locating their learning in the broader ‘map’ of evolving geoscience research.

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GEOverse: An Undergraduate Research Journal: Research Dissemination Within and Beyond the Curriculum

Helen Walkington

1 Introduction

Students studying for their first degree often believe themselves to be recipients of, rather than producers of, knowledge (Jenkins et al. 1998; Zamorski 2002). However, following the work of the Boyer Commission (1998) and Healey and Jenkins (2009) student participation in research and therefore in knowledge creation is a central element of the undergraduate higher education experience. Empowering students as researchers and exposing them to the entire research cycle create the opportunity to participate in an authentic academic research experience, to disseminate research findings to a wide audience, and to develop transferable skills (Rifkin et al. 2010; Walkington 2008; Walkington et al. 2011). Making research work public outside the confines of the curriculum can also contribute to improving motivation to perform at the highest academic level (Walkington and Jenkins 2008).

This chapter takes as its starting point the view that undergraduate research is for all students and should be mainstreamed (Walkington and Jenkins 2008). However, in contrast to the experience of academic staff, the undergraduate experience of the research process (or research cycle) often remains incomplete (Walkington 2012). Research written up for a final project, dissertation or similar capstone experience is usually submitted towards the end of the final year and rarely receives feedback beyond the supervisor or marker, and the research produced is rarely disseminated. This 'gap' in the research cycle (Walkington 2008) can, however, be addressed through approaches to disseminating research work publicly, both within and beyond/alongside the curriculum. This chapter considers undergraduate research dissemination.

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There are many possibilities for disseminating research work. For some, sharing research findings with peers on a course or module may be an appropriate level of exposure, for others research findings may merit presentation at a departmental, university or even national undergraduate research conference (e.g. the British conference on undergraduate research or National Conference on Undergraduate Research in the United States). In both cases

> training in communication is a necessary element of research training at undergraduate level
>
> (Boyer Commission 1998: 24)

A further means of disseminating the results of real-world research which can be accessed internationally for a sustained period of time is through the publication of journal articles.

The number of undergraduate research journals has grown rapidly in the last decade. For example, the US Council on Undergraduate Research website hosted 45 e-journals in 2008 and now (April 2012) hosts 84, displaying a mix of institutional and disciplinary foci (CUR 2012). This perspective chapter outlines how a UK journal, *GEOverse*, was created for undergraduate geoscience students to share their research findings. It briefly outlines the development of the journal, the challenges faced and suggestions for good practice. The journal itself has become a pedagogic tool with postgraduate students reviewing articles and gaining insights into the publication process, and the presence of *GEOverse* as an outlet for research has stimulated curriculum change to university degree programmes across a range of institutions.

2 The Development of Undergraduate Research Journals

Gilbert (2004) argues against dedicated undergraduate research journals and suggests that encouraging publication at undergraduate level could create unrealistic expectations, such as publication becoming a requirement for postgraduate study. A further challenge noted in the literature is that differences in the quality of tutor mentoring can impact on the research design and ultimately the publication potential of student research (Tan 2007). Although the risk of rejection is an authentic real-world process, this may demotivate students if they feel that a lack of institutional support was to blame for their failure to get their work into the public domain and externally recognised. More fundamentally, some authors argue that the curriculum has not sufficiently prepared undergraduates, and even postgraduates, for independent research (DeHaan 2009; Evans and Witkosky 2004; Harrison and Whalley 2008; Lovitts 2005).

In the UK where most journals are relatively new, the majority are created within institutions, at either departmental or institutional level, as a showcase for student work. Whereas institutional journals tend to publish work across the full range of disciplines, there are some dedicated to the geosciences.

Charlesworth and Foster (1996) reported on the impact of an undergraduate journal at Coventry University, UK, linked specifically to two hydrology modules. Although the coursework for the modules began as papers based on primary research, it became necessary to change the requirements to the submission of review articles; this was to overcome the resource constraints posed by large classes. Regardless of the type of papers published, the staff reported that the idea of publication continued to motivate students.

> The most significant benefit is the improvement in motivation. The stimulus is provided by the competition to produce a paper which may be published in the journal.
>
> (Charlesworth and Foster 1996: 52)

Motivation is heightened where emphasis is upon publishing only the highest quality work. In Australia *GEOView* is published online by the Institute of Australian Geographers where it publishes high quality research being undertaken by undergraduate students of Geography and Environmental Studies across Australian universities (see http://www.socsci.flinders.edu.au/geog/geos/index.php).

3 *GEOverse*

GEOverse (see http://geoverse.brookes.ac.uk/) is a national e-journal of undergraduate research in Geography being piloted initially at four UK universities (Oxford Brookes University, the University of Reading, the University of Gloucestershire and Queen Mary College, University of London). It aims to allow students to develop research writing skills in a supportive but rigorous environment of review, to expose students to the process of academic publication and to allow high-quality undergraduate research to be accessed in the public domain (Walkington 2008, 2009, 2012).

Undergraduate students who submit their work to the journal receive supportive and constructive feedback and understand that they are writing for a real but unknown public audience, an important transferable skill. A trained team of postgraduate students from across a growing range of universities form an online editorial advisory board, reviewing articles collaboratively. A shared online space is created for each submitted paper where paired reviewers can see each other's comments, so that a unified response is created for the student author through online dialogue.

4 Undergraduate Geoscience Research

The types of topic which are published in an undergraduate journal may differ from those in standard journals because the time frame for research is much more compressed for undergraduate students. For this reason dedicated journals rather than those shared with postgraduates and academic staff create a more appropriate platform for dissemination.

In the case of *GEOverse*, the use of theoretical ideas to stimulate articles, based on creative assignments that have been set in the curriculum, can form the basis of successful and novel articles. For example, one successful paper was based upon the creation of a conceptual model to aid in understanding the dispersal and deposition of ash from Soufrière Hills Volcano on the island of Montserrat (Pering 2010). Another article examined the likely sequence of events and effects of an impact by asteroid 1989FC on the earth (Gilchrist 2009).

The testing of published theories in the field has also proved valuable for inspiring articles, and when adopting a group-work approach, sufficient data can be generated from a standard 1-week overseas field course. A project on the relationship between crack orientation and solar insolation in WadiShehah, Northern United Arab Emirates (Rewcastle 2008), revealed that assumptions published in the academic literature were not well founded based on work deriving from research carried out in a different desert environment. Also based on the same field trip, the salt weathering impacts on building materials at Jazirat Al Hamra, UAE, were investigated by a group who measured and mapped salinity values and damage to built structures (Bates 2010). As a result of considering the possibility of publication at the time of data collection, student motivation and attention to detail during fieldwork can be enhanced.

In most cases submissions to the journal come from dissertation or final project work where an individual student has had an extended period of independent work supervised by a tutor. One of the key problems is that students lack the self knowledge to judge their own work and prefer to wait until they have had faculty validation by receiving a high grade before being confident to submit their work for publication. This delays the process of submission and often means students who hand in final projects at the end of their final year need to invest time to rewrite the thesis in the format of a journal article in their summer vacation or when they have started full-time employment. The challenge in this situation is to maintain links with students after they have graduated. Unfortunately, some articles never get finished and time spent by the journal team giving feedback on early submissions is wasted. It is therefore desirable to embed article writing and other student research dissemination opportunities within the curriculum.

5 Curriculum Impacts

The presence of *GEOverse* has impacted on the work of colleagues in all the collaborating UK institutions and curricula have been adapted in different ways. *GEOverse* has an ongoing submission ethos dealing with individual articles as they come in, rather than issues and deadlines, making it flexible enough to cope with universities on different semester/term timescales. Colleagues at the University of Reading have chosen one course/module in which the pre-existing examination has been replaced with an assignment based upon writing a journal article for *GEOVerse*. This represents a significant pedagogic shift and clearly demonstrates to students that their research work is valued. The University of Gloucestershire has developed a collaborative writing assignment in which students write a literature-based journal article as a team. In this situation, students benefit from the peer review process as they are constructing their articles. At Queen Mary (University of London), students are given the opportunity to produce a research paper on their return from an Iceland expedition where field data is collected. Therefore, the presence of *GEOverse* allows the curriculum to be reoriented to suit a variety of institutional contexts. At Oxford Brookes University, the Geography programme has been rewritten to support learners from year 1 to year 3 with a dedicated research pathway. This builds up to a final year honours module devoted to the individual (mentored) write-up of a *GEOverse* article deriving from year 2 fieldwork. Students work with a supervisor to write an individual research paper. Draft papers are submitted in week 6 of the semester for formative feedback with an ongoing series of one-to-one tutorials to support the writing process (Walkington 2012).

GEOverse also welcomes articles from any student research, not just from courses that are formally linked through an assignment. Some students who had taken a module/course with an assignment linked to the journal submission guidelines went on to submit their independent study or dissertation work retrospectively as an article when they have received a suitably high grade for it. In all contexts teaching skills in communication and especially the development of writing skills, to support students who take the opportunity to share the findings from their research, is something that can be embedded into the curriculum in order to support students and widen participation in the dissemination process.

It is important to embed a journal within an institution or across multiple institutions so costs such as staff time are covered and shared. If students are involved in running the journal, processes such as copy-editing could be done on a voluntary basis as the students gain valuable transferable skills and experience.

6 Evaluating the Undergraduate Writing Experience

With the author guidelines of *GEOverse* to aim for, several consecutive cohorts of students from Oxford Brookes University (2008–2011) wrote journal articles as coursework assignments (only a small minority then chose to submit their work for consideration to *GEOverse*). Preliminary undergraduate author comments have been reported previously (Walkington 2008) with the most frequent author response being a ‘sense of achievement’. Another frequently mentioned theme was the understanding developed as a result of writing an article, students experienced a sense of their knowledge ‘coming together’. Students clearly enjoyed the freedom of the creative process, being able to think outside the box to report genuinely new findings from their own data.

Detailed analysis (reported fully in Walkington 2012) has revealed a more critical approach to literary sources being adopted by the student authors. Successfully published authors became more critical of what they were reading and avoided sources which were not clearly peer reviewed. They also reported that they had benefited from trusting the advice of (unseen and unknown) reviewers as it had significantly improved their work, despite being frustrated by the fact they could not talk through and clarify the feedback they had been given.

7 Recommendations for Good Practice

Full engagement with the research process can begin to dramatically change the way that students are viewed in Higher Education institutions. Paulo Freire argued that

> Education must begin with the solution of the teacher-student contradiction, by reconciling the poles of the contradiction so that both are simultaneously students and teachers. (Freire 1970, p. 72)

In the recent literature on student engagement, students have been described as ‘consumers’ (Molesworth et al. 2010), ‘clients’ (Bailey 2000), ‘producers’ (Neary and Winn 2009) or ‘co-producers’ (McCulloch 2009) and in some institutions as ‘change agents’ (Kay et al. 2010). The pedagogy of research participation (Lambert 2009) can emancipate learners so that they have an active role in linking teaching and research. The writing, review and publication of undergraduate research have the potential to break down barriers between students and academic staff in a way which engages students with authentic academic processes. Where student research outputs begin to inform the curriculum, we have moved a step further still to resolving Freire’s ‘teacher-student contradiction’.

A further way in which academics can ease the transition for students as they become producers of knowledge is for them to be open with students about the research process and talk about their experience of rejection, rewriting and redrafting and publication success. Some academics share examples of early drafts, reviewer feedback and final articles with their students in an attempt to demystify the research process. This type of activity has the potential to break down barriers between staff and students and engages students in the research culture of the university.

The most successful journals involve students in the production, marketing and management processes of the journal. *GEOverse* relies upon postgraduate reviewers’ involvement as an editorial advisory board. In turn the postgraduate students gain access to a network across multiple institutions, recognition for their academic activity and as a result of carrying out multiple reviews what they call ‘reviewers eyes’, i.e. an ability to critically appraise any piece of writing, their own as well as that of others.

8 Conclusions

The experience of developing and managing *GEOverse* suggests that the student experience of research publication will be most successful where it is carefully scaffolded through the provision of a variety of opportunities within the curriculum which allow students to engage with writing, editing, critically reviewing articles and discussing feedback on drafts and plans for articles in groups or with tutors. The provision of a variety of opportunities for publication of undergraduate research findings beyond the curriculum enhances student engagement with their discipline, boosts confidence and can contribute to a developing sense of belonging to a research community. It allows students to experience the research process in its entirety.

Overview

Status Quo and/or Trends

- Institutional journals are generally showcases rather than being discipline specific. There are a limited number of undergraduate geoscience journals available for students to publish in, these are mainly national level and focussed on top quality publications.
- Geoscience research can be time consuming and is often collaborative so providing opportunities for students to write in collaboration with staff members may be necessary.
- Successful journals involve students in the production, marketing and management processes of the journal.

Challenges to Ovtercome

- Financial sustainability of journals in the long term is a challenge. Many journals are kick-started with small funding grants but become unsustainable if they rely on paying for administration.
- Soliciting articles can be a challenge at the start, one of the largest barriers to students submitting articles is a lack of confidence that their work is of a sufficiently high standard
- Students need to be committed to writing up their work after leaving university, good communication is essential to stay in touch with graduates.

Recommendations for Good Practice

- Use journal articles in the curriculum, particularly articles written by students from the previous cohort as a starting point for further research.
- Use other forms of research dissemination to solicit journal articles such as poster conferences.
- Ensure that journal processes are made transparent by having academics talk about their experience of rejection, rewriting, and redrafting in front of students in order to demystify the process.
- Develop and embed writing opportunities in the curriculum e.g. embedding article writing, instead of writing dissertations or essays.

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Towards Technology- and Research-Enhanced Education (TREE): Electronic Feedback as a Teaching Tool in Geoscience

Vincent C.H. Tong

1 Introduction

Pedagogical innovations involving the use of research content and skills have been made in a diverse range of teaching contexts and institutions (e.g. Healey and Jenkins 2009), and this diversity supports the view that there is a widespread consensus on the importance of integrating research in teaching (e.g. Brew 2010). Apart from research, the application of technology represents another focus in the development of university education as the necessary equipment has become more readily available (e.g. Rogers 2000). This trend is helped by the proliferation of institution-wide virtual learning platforms, on which electronic teaching materials and assessments are hosted. Besides improvements in network infrastructure, learning technologists are instrumental in promoting and supporting the use of technology in education.

These recent developments suggest that both research-enhanced education (REE) and technology-enhanced education (TEE) are of strategic importance in a wide range of universities. TEE is arguably more effective if technology is applied to achieve pedagogical objectives, including the development of research skills and teaching of research content in REE. Given their complementary nature, it is beneficial to identify and exploit synergies between TEE and REE. Amongst other teaching methods, the use of electronic platforms in feedback provision may serve as an effective link between TEE and REE. Electronic feedback already plays a significant role in TEE as the quality and timeliness of feedback on students' coursework have received considerable attention in the higher education community (e.g. Poulos and Mahony 2008). Electronic feedback may therefore be readily applied to REE by serving as a teaching tool in supporting teaching and assessments.

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As the use of electronic feedback is not discipline specific, it has the potential to be adopted widely as an effective teaching tool that forges 'technology- and research-enhanced education' (TREE) across different faculties.

However, the use of electronic feedback in higher education is not without its challenges. First, in terms of its pedagogical potential, feedback provision is usually associated with formative assessments as relatively little or no feedback is traditionally given to students on their summative assessments. Having this conception of feedback provision may significantly limit the range of contexts in which electronic feedback may be used to enhance students' learning. Better awareness of a wider possible range of teaching contexts in which electronic feedback may be given to students, or even by students, will facilitate its development as an educational tool for TREE. Second, despite the increasing popularity of coursework submission platforms with feedback functionalities, the use of electronic feedback is far from universal. Successful implementation of TEE tools ultimately depends on the active participation of teaching staff. Whilst some staff may be engaged in exploring the use of technology in their teaching, it is important to consider how pedagogical innovations can be made readily implementable in a variety of settings. It is therefore useful to rethink the uses of electronic feedback.

The motivation of this chapter is to show how electronic feedback can be used as an effective teaching tool in TREE, particularly in the context of geoscience courses. The pedagogical considerations discussed here are primarily developed from several articles previously published by the author (Tong 2010, 2011, 2012; Tong and Chow 2013). Two cases involving the use of electronic feedback for reinforcing students' research skills in different contexts are discussed (Tong 2011, 2012). Rather than presenting the cases separately, this chapter will instead comprise two thematic sections on (1) the use of electronic feedback as a teaching tool and (2) how it may be used to address some key pedagogical issues in teaching research skills and content. The rationale of this presentation is to foreground the different sets of pedagogical considerations in REE and TEE and to show how electronic feedback may be used to bring them together in geoscience courses.

More specifically, I will discuss how electronic feedback may be used beyond its conventional association with formative assessments in the first part of this chapter. I will focus on how electronic feedback may serve as a flexible TEE platform enhancing the interactions between students and their lecturers. This chapter will also discuss how electronic feedback may be applied to the enhancement of teaching efficiency, which is an important consideration if electronic feedback is to be adopted more widely. This first part of the chapter is therefore applicable to both REE and non-REE. The second part of the chapter will highlight the use of electronic feedback for achieving objectives in REE by integrating different teaching components such as lectures and assessments. There are inevitably some contextual restrictions related to the two examples. Nevertheless, the underlying pedagogical principles are also readily applicable to other disciplines in geosciences and beyond. Electronic feedback is featured here as an illustrative example of a teaching tool that has the potential to be used effectively in bringing TEE and REE together. It is worth mentioning that it is by no means the only effective approach that can be adopted in promoting TREE in higher education. Note that details on the implementation of electronic feedback can be found in Tong (2011, 2012).

2 Rethinking Electronic Feedback as a Teaching Tool in TEE

Before discussing the application of electronic feedback as a teaching tool, it is worth reviewing the nature of feedback used in education as well as how its effectiveness may be assessed. Whilst there is no universally agreed definition of the term ‘feedback’, it can nevertheless be understood as information used for addressing the gap between the actual and reference levels of some parameters under consideration (Ramprasad 1983). This understanding of the term can be applied to two commonly encountered contexts in university teaching: (1) lecturers’ advice to students on formative assessments and (2) students’ comments on lecturers’ teaching. In other words, feedback may be used not only to reduce the gap between the expected and actual levels of students’ work but also to help improve lecturers’ teaching.

As for the effectiveness of feedback, it can be measured by the extent to which the information can be used to alter the gap of some ‘parameters’ (Walker 2009). This consideration leads to, or is at least related to, the idea of ‘feedforward’ (Brown 2007), which is a form of feedback that specifically aims to inform the recipients on how to achieve the expected levels of performance in the future. The concept of feedforward may in theory be applied to students’ comments about their lecturers’ teaching, although this appears to be less common than the advice provided by lecturers on students’ work.

The use of virtual learning platforms, online coursework submission with anti-plagiarism tools, and online communications such as text-based and multimedia messaging has revolutionised how feedback is delivered to students. With the advent of electronic feedback, it is important to consider how electronic platforms can be used most effectively as a teaching resource. One of the key considerations is how feedback delivered by electronic means can be integrated into teaching activities. This integration demands some rethinking of electronic feedback, given that feedback may not only be provided to students but also by students in enhancing the quality of both learning and teaching. In other words, it is necessary to explore the possibilities of how electronic feedback can be used as a two-way ‘forward-looking’ teaching tool between students and lecturers. These pedagogical possibilities extend far beyond the more conventional delivery of feedback on students’ coursework. Two applications, both of which involve using feedback as teaching materials, are discussed. The first example demonstrates its use in assessments, whereas the second one is related to feedback from students to lecturers as a tool for lecturing or for conducting teaching sessions.

2.1 Electronic Study Package with a Feedback and Feedforward Database

This example is about the use of electronic feedback on students' coursework with study materials designed for encouraging students to reflect on their submitted work and on how to improve on their assignments (Tong 2011). In order to provide feedback on students' coursework and to offer study materials to students on an advanced undergraduate geophysics module, an electronic study package was implemented. The study package was presented as an HTML site (i.e. displayable on a browser) with the following main components: (1) personalised feedback on students' submitted coursework, (2) generic feedback and feedforward on common mistakes and a discussion of the academic skills required to complete the coursework successfully and (3) teaching materials on linking the coursework to the course content. The study package was given to all students electronically after all the coursework had been marked. Apart from the benefits of electronic feedback with regard to enhancing students' learning experience, the discussion below will explain the flexibility and efficiency that lecturers may expect from adopting this approach.

Advice on students' coursework is more comprehensive and effective if it contains both feedback and feedforward components. On one hand, feedback should encourage students to use the coursework as a context for improving their understanding of the course materials and skills developed earlier in the course. On the other hand, feedforward should relate the coursework to course content and skills to be introduced and tested in the subsequent parts of the course. Feedback and feedforward are complementary as they together help students develop a more integrated understanding of the subject matter, which is likely to involve building links between different learning activities and assessments. This is important because skills and contents introduced in the course and tested in assessments are often 'fragmented' but interconnected. The joint use of feedback and feedforward may also encourage lecturers to pay more attention to the design of assessments in relation to the overall learning objectives of a module. Figure 1 summarises the relationships between the roles of lectures, assessments, feedback and feedforward.

In order to enhance the quality and efficiency in feedback and feedforward delivery, a database was implemented (Tong 2011). The feedback and feedforward database was a learning resource based on a discussion of mistakes commonly made by students in their coursework, presented in the style of topic-based 'frequently asked questions'. Generic advice on how to avoid these mistakes was also featured. Once the database was constructed, the module lecturer could personalise the generic advice by specifying relevant topics in the feedback and feedforward database based on the submitted coursework. The advantage of using a database in feedback and feedforward provision is that lecturers do not have to rewrite similar comments every time when a previously encountered mistake is found. Contents in the database may be modified and expanded, and more topics may be added to the database for future use. The time saved may instead be spent on improving the quality and scope of the database. Apart from using the specified content from the database,

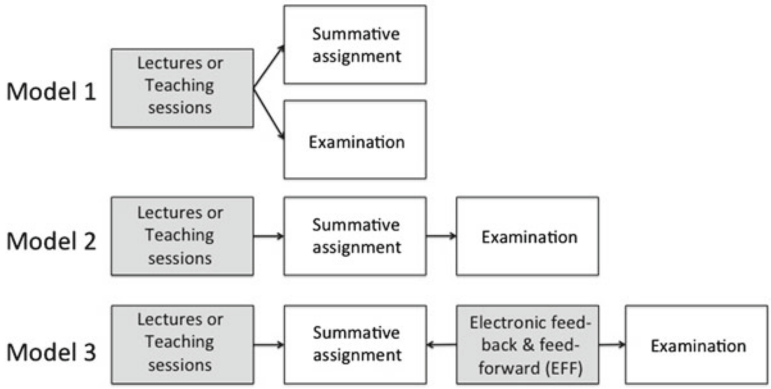


Fig. 1 Models showing different relationships between teaching (*grey boxes*) and summative assessments (*white boxes*) in a module. *Models 1* and *2* show the lack of pedagogical links between summative assessments in conventional module design. The use of electronic feedback and feed-forward in *Model 3* is crucial because it provides effective and efficient links between summative assessments in a module

students may also wish to study other materials in the database. The database is particularly useful as all study advice (i.e. whether specified by the lecturer or not) is presented in the context of an actual assignment, rather than as generic study skills. Feedback databases can therefore be used to enhance the quality and efficiency of providing detailed personalised comments on students' learning difficulties and to function as a useful in-context learning resource at the same time.

Besides enhancing the efficiency in providing effective advice to students, another advantage is that feedback databases may be incorporated into existing online coursework submission systems or institution-wide virtual learning platforms. This integration may even allow the construction of mega-feedback databases that can be shared between different modules or even departments. Furthermore, electronic feedback has also been shown to be more effective than handwritten feedback simply as a result of vastly improved legibility (e.g. Handverk et al. 2000). Video or audio feedback (e.g. Macgregor et al. 2011) may also be readily implemented and linked to the database. However, like all forms of feedback, the use of electronic platform does not automatically guarantee its quality. It is therefore important to consider the relevance to the assessment criteria, clarity of contents as well as timeliness of feedback delivery.

Personalised feedback on students' coursework can be easily achieved by providing hyperlinks to the relevant materials in the feedback and feedforward database. Implementing hyperlinked feedback and feedforward simply requires the use of word processing software, and it is no longer necessary to have specialist knowledge and experience in professional website design. Furthermore, an additional advantage is that there is considerable flexibility in the design and implementation of electronic feedback and feedforward databases. An electronic study package may range from a simple text-based document within which hyperlinks are used to a full-fledged multimedia website with automatic transfer of marks to the central student information system and with separate login accounts for lecturers and students.

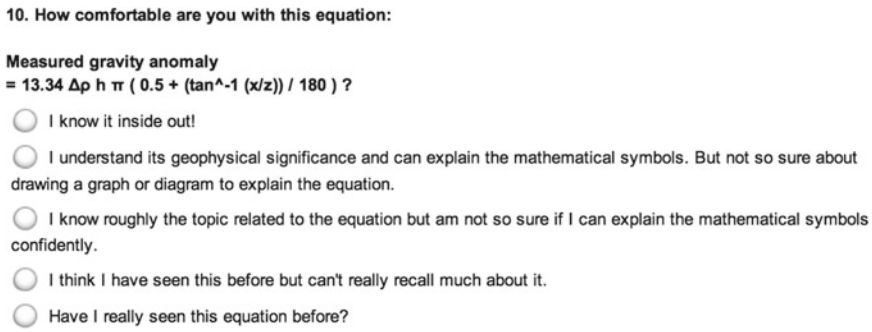
2.2 *Using Electronic Feedback from Students as a Tool in Lecturing*

The use of electronic platforms has helped improve the efficiency in the collection and analysis of student evaluation data. Owing to the conventional timing of course evaluation (i.e. towards the end of a module), students providing feedback on their lecturers' teaching do not normally benefit directly. This is because changes to the teaching are not normally introduced in the same academic year. Moreover, feedback from students is not generally regarded as a teaching tool. However, as demonstrated in the following example, electronic feedback from students may be used to drive one of the most common forms of teaching at universities – lecturing. In Tong (2012), second-year undergraduate students completed an online survey about some key equations taught in their introductory geophysics module. The polling was conducted a few weeks before the revision lecture, whose aim was to help the students prepare for the final examination. The survey was used to structure the follow-up revision lecture as the polling results were released and the equations featured in the survey were discussed. This teaching approach, also known as AESIR (asynchronous electronic survey with in-class revision; Tong 2012; Tong and Chow 2013), may enhance lecturing in various ways. These pedagogical benefits are explained in the following sections.

2.2.1 Asynchronous Feedback

Electronic surveys can be divided into two types according to whether a survey is conducted at the same time when the teaching takes place (i.e. synchronous) or with a time lag between the survey and the related teaching activities (i.e. asynchronous). Synchronous electronic surveys are widely used in lecturing as 'clickers' have become increasingly available in lecture halls or rooms. Students may use clickers to vote when their lecturer poses a question during a lecture, and the students' responses are instantaneously made available and may help make lectures more interactive as a result (e.g. Draper and Brown 2004; Fies and Marshall 2006). In contrast, asynchronous electronic surveys are commonly implemented as feedback-gathering tools (e.g. Moss and Hendry 2002), such as those used in end-of-course evaluations. If used as a tool in feedback collection, asynchronous surveys have limited pedagogical functions. However, as shown in the AESIR approach (Tong 2012; Tong and Chow 2013), asynchronous electronic surveys may be used to prompt students to review course materials without introducing any pressure associated with online tests (Tong 2012).

The implementation of online polling is relatively straightforward as free generic non-subscription surveying websites (e.g. www.surveymonkey.com) are available,



10. How comfortable are you with this equation:

Measured gravity anomaly
= 13.34 Δρ h π (0.5 + (tan^-1 (x/z)) / 180) ?

- I know it inside out!
- I understand its geophysical significance and can explain the mathematical symbols. But not so sure about drawing a graph or diagram to explain the equation.
- I know roughly the topic related to the equation but am not so sure if I can explain the mathematical symbols confidently.
- I think I have seen this before but can't really recall much about it.
- Have I really seen this equation before?

Fig. 2 An example of a question used in pre-lecture asynchronous electronic survey. Note that the question is presented as a way to gather students' opinion and is not in the form of an online test

and survey results can be readily analysed and displayed on a computer. Although entering survey questions onto the online platform can be done relatively quickly, it is the design of the survey questions that demands more careful planning. This is because the survey questions and the polling results are central to driving the student-centred and interactive follow-up lecture. Although the use of online platforms may make polling and feedback collection more efficient, pedagogical considerations such as the order of the survey questions and the way in which the questions are presented are vital to its successful implementation.

Clicker-based electronic surveys used in lectures usually consist of simple test-like questions requiring students to think about the course materials introduced in the lecture, and these synchronous surveys may therefore be somewhat similar to 'online tests'. Asynchronous electronic surveys may also include questions that resemble online tests. Alternatively, asynchronous surveys may be implemented in the form of pre-lecture learning activities without featuring any test-like questions. Survey questions may be used to gauge the students' opinions about their learning (Tong 2012), such as how comfortable they are with some specific aspects of the course (Fig. 2). In fact, what makes the use of online survey in AESIR different from online assessments is that they are real surveys of 'opinions' and that they do not function as tests.

2.2.2 Teaching Driven by Students' Asynchronous Feedback

The use of asynchronous feedback from students also differs from clicker-based synchronous interactive lectures in other respects. For instance, lecturers adopting the AESIR approach have time to use the feedback to structure the follow-up lectures. By analysing the students' feedback, lecturers may allocate more time for explaining the concepts that the students find challenging. As for the students, the release of online survey results during the lecture may make the learning experience more engaging (Tong 2012). With the release of survey results, some students felt more motivated in their study because they realised that there were others in the class who might also be struggling to have a thorough grasp of the concepts introduced in the course (Tong 2012).

However, the use of electronic feedback in the form of online surveys also has its challenges. As reported in Tong (2012), there are concerns that 'survey fatigue' may develop because students may become less incentivised to participate in online surveys on a regular basis. Despite this potential concern, the use of pre-lecture surveys may nevertheless help make lectures a more interactive teaching-and-learning activity, not only during the lectures but also before the lectures. The students will be more prepared for the materials to be covered in the follow-up teaching, and the lecturers will be better informed with regard to their students' learning needs. Moreover, survey-driven lectures are likely to benefit a wide spectrum of students. For instance, the release of online survey results in the follow-up lectures may also motivate students who did not participate in online surveys. In fact, as shown in Tong and Chow (2013), these students were equally positive about the use of the survey-driven revision lecture as those who did participate in the pre-lecture online surveys. It is also worth noting that the application of AESIR is not restricted to revision lectures but may be tailored to suit any form of teaching. In other words, the post-survey revision lecture in Tong (2012) may be replaced by tutorials, for instance. In the context of geosciences, it is also possible to design online surveys before a field trip, with the aim of linking the theories introduced in related lecture-based modules to the field-based activities.

3 Using Electronic Feedback for REE in Geoscience

After outlining the wider pedagogical uses of electronic feedback, I will discuss how it can be applied to developing students' research skills in geosciences. In this section, I will show how electronic feedback may serve as a tool linking the different module components such as lectures and assessments. The two cases show how electronic feedback was used to address specific teaching and learning objectives in REE. The first case will be about the reinforcement of students' research literature reviewing skills, whereas the second case will be on the development of quantitative skills in the context of REE. In both cases, research articles play a key role in achieving the research-related objectives, with electronic feedback functioning as a bridge linking REE and TEE.

3.1 Reinforcing Research Reviewing and Reporting Skills

3.1.1 Pedagogical Rationales

Geoscience is a highly interdisciplinary subject, incorporating various branches of physical, biological and mathematical sciences. It goes beyond the traditional boundary of geology and has evolved to become a subject that seeks to understand the interconnected mechanisms of the Earth as a system. In fact, its ever-expanding scope now incorporates elements of planetary science and space science. As a rapidly advancing interdisciplinary area of study, it is important for students to study a diverse range of the latest scientific advances that go beyond conventional disciplinary boundaries. Students therefore need to develop the ability to review and synthesise research findings from a diverse range of sub-disciplines. The case of promoting REE in geoscience is particularly strong and will be successful if the interdisciplinary nature of the subject is addressed.

3.1.2 Application of Electronic Feedback on Students' Assessed Coursework

Studying articles reporting novel interdisciplinary research encourages undergraduate students to develop the sense that it is normal to go beyond conventional disciplinary-based boundaries in scientific research (Tong 2010). Perhaps equally importantly, interdisciplinary research articles also provide excellent materials to test students' ability in applying their understanding of scientific theories to less familiar contexts. In other words, coursework based on interdisciplinary research articles may be set for encouraging students to apply their scientific knowledge and to develop a deeper appreciation of this type of research. As discussed in Sect. 2, electronic feedback may serve as an effective and efficient teaching tool based on submitted coursework. To illustrate how this may be implemented in practice for reinforcing students' research skills, the use of electronic feedback in an advanced undergraduate module in geophysics (Tong 2011) is discussed as follows.

The learning objectives of the advanced geophysics module comprised two elements: (1) the understanding of advanced geophysical theories and (2) the application of these theories through reviewing some selected research articles in geophysics. The students were expected to demonstrate these skills in the summative assessments, which consisted of one piece of coursework submitted at the end of the module and one final written examination. The coursework invited the students to demonstrate their understanding of the geophysical theories taught in the module by writing a critical review on four research articles. These articles reported novel interdisciplinary research and were published in leading international scientific journals such as *Nature* and *Science*. The coursework therefore not only tested the students' understanding of the related scientific theories and research literature reviewing skills but also introduced them to the world of novel transdisciplinary research in geosciences.

As undergraduate teaching normally consists of multiple teaching-and-assessment elements, it is crucial that these components are integrated to provide a coherent learning experience for the students. It is also important that the learning outcomes and the assessment objectives are aligned. Electronic feedback and feedforward may provide a platform to link these different course components. In the example above, the three main module components were identified as lectures, assessed coursework and the final examination (Tong 2011). The objectives in REE would be best achieved if the students' experience in reviewing the interdisciplinary research articles in the assessed coursework could be used (1) in contexts beyond the coursework, (2) to improve their research reviewing and reporting skills in the preparation for the final examination and (3) to develop a deeper understanding of transdisciplinary research after the coursework is completed.

In Tong (2011), these objectives were achieved by providing electronic feedback and feedforward to students on their submitted coursework (Sect. 2.1). Hyperlinked study advice from an electronic feedback and feedforward database was given in the context of the coursework. The teaching materials in the database were designed to encourage the students to reflect on their learning experience based on the coursework. The aim was that they would be able to improve their research reviewing and synthesis skills as they prepare for the final examination. The teaching materials in the feedback and feedforward database were effectively used to link the two summative assessments (i.e. coursework and final examination), and this represents a non-conventional approach to module design involving assessments (Fig. 1).

3.2 Linking Quantitative Skills to Research Contents

3.2.1 Pedagogical Rationales

Although the development of quantitative skills normally forms an integral part of their undergraduate programmes, geoscience students often find modules with an emphasis on quantitative skills particularly challenging (e.g. Macdonald et al. 2000). As geoscience is a multidisciplinary science subject, it is important that all undergraduates following these programmes should reach a sufficient level of mathematics for their studies. The following considerations may be relevant in determining the level and types of mathematical skills students needed. First, the students' level of mathematics should allow them to engage fully with course materials typically covered in the more quantitative sub-disciplines, including the study of more advanced, original research materials in these subjects. Second, the study of mathematics should also prepare students for participating in enquiry-based studies, including field-, laboratory- or computer-based projects.

In both cases, the emphasis should not be based purely on the teaching of mathematical theories but on the application of mathematics to a diverse range of contexts in Earth sciences. The exact levels and scope of quantitative skills of course depend on the students' specialisations as well as their academic background. However, an explicit development of applied mathematical skills for both theoretical and enquiry-based studies is likely to benefit students on all undergraduate geoscience programmes. One possibility is for lecturers to explain the links between (1) mathematical equations learnt during a module and (2) the relevance of the equations in understanding studies reported in research articles. As explained in the following example, making the link between mathematics and their applications in published research can be done effectively during the revision lecture before the final examination. Pre-lecture electronic feedback from students with follow-up lectures may serve as a tool to drive interactive teaching and learning, which was demonstrated in Sect. 2.2.

3.2.2 Application of Electronic Feedback from Students

In Tong (2012), electronic feedback from an online poll was used to prepare the undergraduate students for a pre-examination revision lecture as part of an introductory geophysics module taken by second-year undergraduate students. As demonstrated in this chapter, electronic feedback may be used to link different learning and teaching activities. To prepare the students for the final examination, the revision lecture was aimed (1) to reinforce the students' understanding of some key equations introduced in the module and (2) to link these equations to their geophysical applications in some research articles already studied in the module.

The students were first invited to complete an electronic questionnaire consisting of ten multiple-choice questions, which asked them how comfortable they were with the key equations introduced in the lectures (Tong 2012). An example of a survey question is shown in Fig. 2. The questionnaire did not require the students to do any preparation before participating in the survey, and the survey was deliberately presented not in the form of an online test but as a survey. The result of the survey, the survey questions and the equations themselves were used to structure the revision lecture. As the survey was totally anonymous, students would not be motivated to lie about their understanding and learning needs. This was in fact confirmed by the student evaluation reported in Tong (2012).

In terms of the objectives in REE, the equations featured in the pre-lecture survey played a central role in driving the discussion of their geophysical applications in the context of the research articles studied in the module. In other words, in order to make this pre-lecture feedback work successfully, it was vital that the survey questions were presented in such a way that they served as the backbone of the lecture plan. Whilst there is no substitute for good lecturing, the use of pre-lecture electronic feedback from students and the release of survey results during the lecture have been shown to facilitate the teaching in the follow-up revision lecture (Tong 2012).

4 Conclusions

The flexibility and versatility of electronic feedback as a teaching tool were illustrated by two examples in this chapter. The implementation of an electronic study package, which comprised an electronic database with hyperlinked teaching materials, shows that feedback can function as an important component that is fully integrated into the teaching of a module. The use of pre-lecture electronic feedback from students to their lecturer may significantly enhance the interactivity before and during lectures. It should also allow lecturers to address their students' learning needs more effectively. On the basis of these examples, the use of electronic feedback can be expanded significantly beyond its more conventional association with formative assessments and teaching evaluations. When compared with traditional, non-electronic forms of feedback, the use of technology is likely to enhance the efficiency and quality of teaching (e.g. Laurillard 2008). Apart from these advantages of adopting electronic feedback as a tool in TEE, its implementation is relatively straightforward. With no specialist knowledge required in its implementation, the technology itself is unlikely to pose any significant technical barriers preventing its adoption.

On a different front, this chapter also outlined the rationales for developing geoscience students' research literature reviewing, reporting and quantitative skills. In particular, research articles may provide a key, readily available resource for supporting teaching and learning activities, and two cases were discussed. First, given the multidisciplinary nature of geosciences, novel interdisciplinary articles may be used to develop students' awareness of this type of research, which has become increasingly common in the study of the Earth as a planet. These articles also provide excellent materials for testing students' understanding of the related scientific theories as well as their research reviewing and reporting skills. Second, the development of quantitative skills in geoscience programmes should be considered in the context of REE. Linking mathematical skills to the study of research articles with quantitative content may help students develop a deeper understanding of the relevance of mathematics in scientific research. These mathematical skills may also be useful in conducting small-scale research projects, which often form part of their undergraduate studies.

As shown in these two cases, it is important to recognise the need for careful design of assessments. This is because assessments play a crucial role in the reinforcement of research skills introduced and developed in a module. Electronic feedback may serve as an effective teaching tool that links different teaching components such as lecturing and assessments in REE. As discussed, an electronic study package was used to reinforce the students' research reviewing and reporting skills. This was achieved by encouraging the students to reflect on their submitted coursework, which was based on reviewing some interdisciplinary research articles. The students were also encouraged to use the electronic feedback and feedforward for improving their skills in their preparation for the final examination. The second example involved obtaining pre-lecture electronic feedback from students to drive the planning and teaching in the follow-up revision lecture, which was designed to bring together the use of equations and research articles studied earlier in the module.

In conclusion, the use of electronic feedback provides an effective, flexible and easy-to-implement tool to link teaching and assessments. This link is key to the enhancement of the quality and coherence of the teaching of research skills and content in undergraduate modules. Although electronic feedback is a useful and efficient teaching tool, it is certain that it only represents one of the many applications of technology that will aid the development and adoption of TREE in the coming years. One of the future challenges therefore lies in the identification of the pedagogical applications of other technology-based methods in promoting the integration of research in teaching. Exploiting the complementary nature of TEE and REE through novel applications of teaching platforms may help drive the enhancement of university teaching across different faculties even further.

Overview

Status Quo and/or Trends

- Research and technology have played important strategic roles in driving the enhancement of teaching in higher education.
- Given their complementary nature, it is beneficial to identify and develop potential synergies between research-enhanced and technology-enhanced education.
- Electronic feedback has traditionally been associated with formative assessments and teaching evaluations. As a flexible technology platform, its pedagogical potentials have not been fully exploited.

Challenges to Overcome

- Providing effective electronic feedback on students' work may require significant time input. The use of electronic database with hyperlinked teaching materials may help lecturers improve the quality and efficiency in providing personalised advice to students.
- The interactivity between students and their teacher before and during lectures is often inadequate. Pre-lecture electronic feedback from students may be used to help lecturers better understand their students' learning needs and to structure lectures. Electronic feedback can be applied simultaneously to encourage students to engage with course materials before and during lectures.
- Geoscience students often find mathematical concepts challenging, and inadequate grasp of mathematics may affect their research projects that often require the application of relevant mathematical skills. In addition, students' research literature reviewing and reporting skills are not often taught. In both cases, research articles may be effectively used with electronic feedback to help students reinforce their relevant study skills.

Recommendations for Good Practices

- As a flexible and versatile opinion-gathering platform, electronic feedback can play a more central role in university teaching by building close links between teaching components such as lectures and assessments in a module. It is important to explore and exploit the potential of using technologies in achieving teaching objectives.
- Research-enhanced teaching may be further enhanced by the use of technology, and this is exemplified by the use of electronic feedback in innovative ways to enhance the efficiency and quality of the interactions between lecturers and students.
- Apart from electronic feedback, it is important to develop other flexible, time-efficient and versatile technology-based teaching platforms for promoting technology- and research-enhanced education across different faculties.

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Part V
Pedagogical Examples: Programme Design

Introducing University Students to Authentic, Hands-On Undergraduate Geoscience Research in Entry-Level Coursework

Laura Guertin

1 Introduction

The Council on Undergraduate Research (CUR) is a nonprofit educational organization that mentors university faculty in developing and sustaining undergraduate student research investigations (for the purposes of this chapter, the term "undergraduate" refers to students in the equivalent of grades 13 through 16 in the American higher education system). CUR defines undergraduate research as "an inquiry or investigation conducted by an undergraduate student that makes an original intellectual or creative contribution to the discipline" (Wenzel 1997). The first part of the definition states that research is original work and is, therefore, aimed at creating new knowledge. The second part of the definition states that the work is intended as a contribution to the discipline, implying that the results should be disseminated to the professional community through acceptable media, such as conference presentations and scholarly publications. Halstead's (1997) definition is in agreement, that undergraduate research "must be an original investigation that the student engages in for a significant period of time… a student collaborates with a faculty member on an ongoing long-term project, usually initiated by the faculty member. The project is expected to be funded… and to result in publication in a peer-reviewed scientific journal."

These descriptions of undergraduate research imply that undergraduate research is for students in advanced standing with a long enough period of time and mastery of content to be able to create new knowledge that is then published through a respected journal. There is no disagreement that undergraduate research offers many benefits to students, including advanced cognitive and intellectual growth, professional growth and advancement, and personal growth (Osborn and Karukstis 2009).

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However, there is no reason undergraduate research experiences have to be so rigorous in their structure and execution.

Beckman and Hensel (2009) have published an excellent article that assists faculty in understanding a range of dimensions to undergraduate research. Their working definition asks faculty to think of undergraduate research as several categories that fall along a continuum. For example, research experiences can range from student initiated to faculty initiated, interdisciplinary to disciplinary, and original to the student to original to the discipline. I would add to their model the continuum of introductory level to advanced level, and course based to outside of a course.

It should not be a surprise that undergraduate research projects already exist embedded in courses offered for students in their first 2 years at a university. In fact, Cejda (2009) reports that at 2-year colleges in the United States, undergraduate research is typically found on campus as a component of the curriculum rather than a component of a faculty research agenda. I share my insights and experiences with conducting undergraduate research in my introductory-level geoscience courses and the importance of making those research experiences as authentic and applicable as possible.

2 Trends

In the approximately 15 years I have been teaching geoscience and geography courses in higher education, I have not seen a change in how to categorize the students enrolled in my courses – the students are primarily first- and second-year university-level students, nonscience majors, looking to enroll in the course to satisfy a curriculum requirement (at my university, no matter what major a student is pursuing, he/she must take three science courses for graduation). However, I have seen a notable shift in student expectations, attitudes, and levels of engagement in and out of the classroom. Students are still drawn to geoscience courses for the hands-on exercises carried out during the laboratory periods, especially the times we are outdoors doing our work, whether it is on campus or at sites in the region. Both my colleagues and I have moved away from the "cookbook" laboratory exercises provided with textbooks and laboratory manuals. These prefabricated data and exercises are typically designed in a linear fashion for students to reach a solution to a proposed set of prompts. These exercises do not effectively engage students nor do they provide students with an authentic research-based experience driven by inquiry (Rissing and Cogan 2009).

I have seen my students grow increasingly interested and concerned with the intersections of science and society, especially with reference to natural disasters and hazards and natural economic resources. I know there are faculty in all disciplines who have heard from students, "so how does this apply to me?" Fortunately, the faculty are also hearing the follow-up question, "so what can I do about this?" Students are looking for ways to see the applicability of what they are learning and how they can take action to contribute solutions to today's global challenges.

I am also seeing a change in who is sitting in my classroom. I am seeing a decrease in the traditional-aged college student and an increase in the nontraditional student – the parent that dropped out of school to raise a family now coming back, the serviceman returning from military service overseas (Brown and Gross 2011), etc. My nontraditional students have strong ties to the local community, as do the traditional-aged college students who have decided to continue living at home instead of in on-campus dormitory housing to save money. Overall, there is an increase in the culture among my students to be connected to their local communities, and students are looking for additional ways to give back to local organizations beyond volunteering outside the classroom.

The Project Kaleidoscope (2006) report *Recommendations for Urgent Action* further supports what I am seeing in student expectations, stating that each undergraduate student should be (1) challenged with inquiry-based learning for a deep understanding of science, mathematics, and technological tools and (2) have research opportunities beyond the classroom and campus to connect student learning of content and skills in STEM (science, technology, engineering, math) fields to the world, so students appreciate the relevance of their studies and consider STEM careers. Undergraduate research provides the opportunity to address the demands and expectations of the changes in my classroom. By providing authentic experiences that allow students to learn the geoscience content while developing essential skills, I am avoiding the non-engaging "cookbook" exercises where students can find little relevance and applicability to their local community.

3 Challenges to Overcome

Introductory-level geoscience courses are filled with students receiving their first formal introduction to the content of the discipline. For many students, it may be their first and last opportunity to be instructed in the geosciences. This creates a challenge for faculty, as without a strong foundation and understanding of geoscience, students lack the preparation necessary to complete a research project in this discipline. However, I have found that beginning undergraduate research in introductory-level courses allows for students to develop several valuable research-based skill sets. These research skills provide a solid foundation where the skills they learn can be applied and further developed in upper-division courses, which will then prove useful in future careers. Some of the fundamental undergraduate research skills students can be introduced to and develop may include learning how to complete a literature review, how to process and graphically represent data, how to work as a team, and how to see research through to completion (Guertin and Esparragoza 2009).

Many geoscience and geography courses take advantage of the natural, outdoor environment. I have seen that bringing students outside, even if they are still doing laboratory work on campus, gets them excited and engaged to learn.

Certainly, much geoscience-based research is grounded in data that can be collected from outdoor locations, which then provides a natural environment for undergraduate research projects. However, not all university campuses, especially those located in urban areas, have access to geologic outcrops, rivers and streams, etc. The initial hands-on geoscience experience that has served as the foundation for so many geologists to pursue this career field may not be accessible to students during the early years when they are deciding upon a degree program. Not getting outdoors can limit the opportunity to provide the authentic research experiences students are looking for.

For some faculty, there is the concern of having enough time during a semester to complete all the course objectives and to cover all the course content. Embedding inquiry-based activities into the introductory-level geoscience classroom requires in-class time, from introducing the activity to students to carrying out the exercise to completing the analysis and dissemination. For example, when I take the students in my oceanography course to the Atlantic coast to complete a temporal and spatial investigation of beach profiles, we utilize handheld technology as a data collection tool (Guertin 2006). This requires that I take time to train students on how to use the handheld technology to enter and download the data, before I then train the students on how to work with and plot data in Microsoft Excel. Faculty such as myself quickly learn we have to sacrifice covering course content to make room for research-based experiences during the term.

4 Recommendations for Good Practices

As stated previously, faculty should not feel obligated to follow the strict definition of undergraduate research when integrating research experiences into introductory-level courses but instead revisit Beckman and Hensel's (2009) range of dimensions to undergraduate research. A review of these various components and practices of undergraduate research can remind us that we can design opportunities for students to receive an early and effective student-centered, inquiry-based experience.

One practice for developing student participation in discipline-based projects would be to engage introductory-level students in local-to-international "citizen science" programs. Citizen science programs are led by professional scientists but allow, even encourage, amateur and nonprofessional scientists in the process of collecting and entering data online for projects that may be too large in size and scope for the primary investigators. I have had students contribute to citizen science programs, such as EarthTrek's Gravestone Project (http://www.goearthtrek.com/Gravestones/Gravestones.html), a project that aims to map the location of graveyards around the globe and then use marble gravestones in those graveyards to measure the weathering rate of marble at that location. My students have also contributed to the World Water Monitoring Challenge (http://www.worldwatermonitoringday.org/), an effort that engages global citizens to conduct basic monitoring of their local water bodies. With both of these projects, my students practice data collection and analysis and have the opportunity to access the data already entered into these databases for a global comparison. This scales up the project in its rigor and expectations for synthesis and evaluation of data.

Faculty may be able to find local community partners that have an identified need that even an introductory-level student group could assist. In my geoscience and geography courses with an outdoor laboratory component, I have had groups of students complete GPS mapping of trails at a local arboretum (Dufoe and Guertin 2011; Orner et al. 2011) and create an enhanced podcast of environmental information for a walking trail in a state park (Woodruff et al. 2009). Informal science education centers, such as museums, also offer the opportunity for students to conduct research to benefit their outreach efforts. For example, I had two students in a course I was teaching about dinosaurs who decided to pursue a project that allowed them to take their dinosaur content knowledge and combine their communication technology skills to create an online video to present unique dinosaur knowledge to virtual museum visitors (DiLauro et al. 2010).

I encourage faculty to pursue interdisciplinary projects with colleagues across their university, not only to inspire their own "out-of-the-box" thinking and approach toward developing undergraduate research projects but to demonstrate to students the interdisciplinary nature of the geosciences. A year ago, I was at a university function where I was sitting across the table from a faculty member in the department of music education. My colleague was describing one of the challenges her preservice teachers face in the elementary-school classroom, with static maps and world music presented as a set of disjoined facts. I described how Google Earth could be a tool to facilitate the delivery of music, images, landforms, etc., all in one interface. Since our first meeting, we have had graduate students and undergraduate students bridge the disciplines and create music education curricula enhanced with geospatial technology (Clements and Guertin 2011).

5 Conclusions

Introductory-level geoscience courses can be designed to provide undergraduate students the opportunity for early, authentic research experiences. These inquiry-based opportunities can be conducted in conjunction with global citizen science projects, for community partners, or across university disciplines. Even for students not pursuing a career in the geosciences, an undergraduate research experience will provide students content knowledge and skill sets that can be applied to future studies and careers.

Overview

Status Quo and/or Trends

– Geoscience classrooms are moving away from “cookbook” exercises provided in laboratory manuals with prefabricated data designed for students to reach a solution to an experiment. Increasingly, geoscience courses have students engage in authentic research-based experiences, driven by inquiry.
– Students are establishing connections to their local communities and are looking for additional ways to give back to local organizations beyond volunteering outside the classroom, and research can allow students to do so.
– Students are growing increasingly interested and concerned with the intersections of science and society, especially with reference to natural disasters and hazards and economic resources. Students are looking for ways to contribute solutions to today’s global challenges.

Challenges to Overcome

– Students enrolled in introductory-level geoscience courses are learning the content knowledge of the discipline for the first time. Without a strong foundation and understanding of geosciences, students may lack the preparation necessary to complete a discipline-based research project.
– Geoscience-based research can be grounded in data collected from outdoor locations. However, not all university campuses, especially those located in urban areas, have access to geologic outcrops, streams, etc. The initial “hands-on” experience that served as the foundation for professional geologists to pursue this career field may not be accessible to students during the early years when they are deciding upon a degree program.
– Embedding inquiry-based activities into the introductory-level geoscience classroom requires in-class time, from introducing the activity to students to carrying out the exercise to completing the analysis and dissemination. Faculty may have to sacrifice covering course content to make room for research projects during the term.

Recommendations for Good Practices

– Inquiry-based course projects can be designed for students to collect data to contribute to a larger, existing ongoing research program. For example, several “citizen science” programs exist to which students can contribute.
– Faculty should seek out local community partners that have an identified need that a student group could help fill.
– Interdisciplinary projects allow faculty to connect across their university as well as demonstrate for students the interdisciplinary nature of the geosciences.

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Engaging First-Year Students in Team-Oriented Research: The Terrascope Learning Community

S.A. Bowring, A.W. Epstein, and C.F. Harvey

1 Introduction

We consider it essential that all undergraduate students have some knowledge of the Earth system, in areas that range from its inherent complexity to sustainability and our interaction with the environment. Since a class in this topic is not required at the Massachusetts Institute of Technology (MIT), we attempt to reach a broad cross section of incoming students, regardless of their intent to major in a particular field, in research-enhanced education focused on some aspect of the Earth system, through a program called Terrascope (http://web.mit.edu/terrascope/www/). Our emphasis is on using a multidisciplinary approach to show that understanding the geosciences, from fossil fuels and energy to water resources, to climate change, the health of the oceans and beyond, will underpin what will become their world view, whether they know it or not. We believe it is our responsibility to teach as many students as we can about the Earth system, and in our experience, students who have gone through the Terrascope program have a greatly expanded consciousness about the Earth and humans' effect on it.

Terrascope is a learning community for freshmen (first-year students) at MIT, offered by a partnership between the Departments of Earth, Atmospheric, and Planetary Sciences (EAPS) and Civil and Environmental Engineering (CEE); the program

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derives its support largely from MIT's Office of the Dean for Undergraduate Education (DUE) through the Office of Experiential Learning (OEL). Participation does not require an interest in EAPS or CEE, only a desire to learn in a new environment. It combines the development of a community of like-minded students with academic advising and learning experiences not commonly found in the freshman year.

Incoming students have a number of options for both learning communities and advising, and the choices are made by the middle of June. While we do not actively recruit, students learn about the program by accessing the MIT webpages for new students. The Terrascope websites are updated in early May to include the past year's activities as well as an introduction to the new topic for the coming year. The timing is driven largely by MIT's advising system: Terrascope faculty and staff serve as academic advisors for Terrascope students, and so it is important to know—to the extent possible—which students will be in Terrascope, before advisers are assigned. Students take the fall Terrascope class (see below for a full description of the academic program) as an optional add-on to their regular MIT course load; they receive only general elective credit for the class. One of the spring classes (Terrascope Radio, see below) fulfills Arts and Communication-Intensive requirements, but the other spring class, like the fall class, fulfills no specific requirement. Terrascope is thus a voluntary community: no one is in it who does not want to be part of the program.

Fundamentally, the Terrascope program is about teaching students how to use teamwork to solve complex, interdisciplinary problems that are broadly related to the general themes of the Earth system, environmental issues and sustainability. Terrascope is also about enhancing students' communication skills, both in the classroom and with the general public, both online and through informal and formal presentations. Terrascope has been operating for more than a decade, and it has evolved as we have learned how best to conduct such a unique program. We encourage students to stay involved with Terrascope throughout their time at MIT and beyond, and we offer them formal opportunities to do so. Students cite the program as an extremely important part of their MIT experience, something that shapes their approach to education and work both at MIT and afterward. Many Terrascope students take on leadership positions in departments, classes, and campus organizations, and they tend to seek out and become actively engaged in complex, multidisciplinary group projects. One of the important observations we have made is that Terrascope attracts students with diverse interests, and these students go on to major in a broad cross section of schools and departments at MIT; EAPS and CEE do not attract a disproportionately high number of Terrascope students.

Terrascope has evolved in many ways since first developed by then MIT Professor Kip Hodges (now at Arizona State University) and Penny Chisholm (MIT). Since Terrascope's inception, we have collected both quantitative and qualitative assessments of the program. Some of those studies, and the history of the program's early evolution, are discussed by Lipson et al. (2007) and Epstein et al. (2006). Some outcomes for students, particularly those having to do with students' enthusiasm for research and complex problem solving during and after their later years at MIT, are discussed by Epstein et al. (2007, 2009). The present chapter will focus on the academic components of the program, as it currently exists.

2 The Structure of Terrascope

The guiding philosophy behind Terrascope is that from the first day of class, we treat the students as researchers in science, engineering, and social sciences, not teenagers just out of high school. We have high expectations of their ability to take responsibility for their own learning process, and we make sure the students understand that. This is very different from what they are exposed to in the large physics, math, and chemistry classes that most students take at the same time. Of course, the great majority of our students do not yet have significant research experience; part of the challenge they face is to develop appropriate research skills quickly and in the context of a specific problem. As we describe below, they are provided with a wide variety of personnel (including faculty, staff, peers, and alumni) to whom they can turn in developing those skills; part of their responsibility is to decide how best to use those resources.

Students who enroll in Terrascope are automatically registered for a fall-semester class centered on a particular theme or problem, which changes every year. Participation in this class is the program's only formal requirement. Past problems have included designing a new tsunami warning system, developing a plan to greatly reduce greenhouse gas emissions, and stopping the impending collapse of the global fisheries. In the spring there are two additional, optional classes, as well as a field trip based on the yearlong theme. The fall class is offered by EAPS and represents entitled Solving Complex Problems; it is also known as Mission 20xx where xx is the expected graduation year of the entering freshmen. One of the spring classes, offered by CEE, is called Design for Complex Environmental Issues: Building Solutions and Communicating Ideas (primarily known to students by its MIT subject number, 1.016); it builds on the accomplishments of the Mission class but focuses more tightly on specific aspects of the year's problem. In the other spring class, called Terrascope Radio, students learn how to record, script, edit, and produce radio programs focused on communicating information related to the year's topic to general audiences. Some students take both classes in the spring, some take just one, and some take neither. In all Terrascope classes, students work in teams of various sizes, and in all of the classes, students have great autonomy over their process and ultimate product. One of the core ideas of the program is to put students in charge of their own learning experience. There is also a field trip offered over spring break during which students travel, often internationally, to a place where they can see first-hand some of the issues they have been grappling with.

Terrascope classes may be viewed as examples of the educational approach known as "problem-based learning" (PBL). Definitions of PBL vary, but typical definitions may be found in Hmelo-Silver (2004) and Barrows (2002). PBL as it is now known has its origins in medical education (Savery 2006; Barrows 1996), but in recent decades, its use has spread to a wide variety of fields and curricular areas, including engineering and the sciences. As indicated by multiple analyses and meta-analyses (see, e.g., Strobel and van Barneveld 2009; Gijbels et al. 2005; Hmelo-Silver 2004), PBL is particularly effective in promoting: long-term retention of knowledge and skills; an intellectual emphasis on meaning/understanding rather than reproduction/memory; the ability to apply acquired knowledge in practice, intellectual flexibility; and the development of intrinsic motivation. One of the core goals of Terrascope is to promote these characteristics in freshmen as they begin their MIT education, making PBL an ideal approach for this program. We note that some studies suggest that traditional instruction may be more effective than PBL in promoting discipline-specific knowledge; our undergraduates already receive a strong dose of such discipline-oriented knowledge through traditional instruction in their required core classes, and thus, it is not necessary for Terrascope to fill this role.

3 Terrascope Resources

An important part of the success of the program is the participation of a large number of students, staff, and volunteers, in addition to regular faculty. The three main groups are undergraduate teaching fellows (UTFs), MIT library staff, and alumni mentors. The UTFs are drawn from upper-level undergraduates who took part in the Terrascope program as freshmen. For the fall class typically between 10 and 15 UTFs serve a total population of 80–100 freshmen. UTFs are assigned to small subgroups of freshmen, and they serve as mentors and cheerleaders for those groups. This is especially important toward the end of the semester, when the freshmen are working very hard to complete their project. The MIT library staff is a valuable resource for the students, and we work hard to educate the students about all of the library resources that are available. We find that this detailed training puts them at an advantage over other MIT students. Alumni mentors are MIT alumni from a wide range of departments and graduation years (1960–2012) who are available to help the students formulate solutions, steer them toward resources, and provide support. We have a very active group of mentors from across the country; some come to class every day, others make one or two visits to the class per year, and others communicate primarily via email. The alumni mentors are a very important part of the total success of the program.

4 Fall Semester: Solving Complex Problems (Mission)

This class is distinctly different from nearly all the other classes that freshmen take in their first semester, as it does not have regular homework assignments, exams, and lectures. This comes as a shock to many of the students on the first day of class, and some decide early in the semester that the perceived lack of direction and structure is not for them. The Mission class often starts with more than 100 students, and it is not uncommon to lose a third by the end of the third week. Students who continue past this point generally become deeply engaged in the class, committing far more time and effort to it than would be justified solely by the number of credits they will receive.

We fully understand that the students are not experts in the year's topic and stress that oftentimes it is new thinking, not hindered by accumulated dogma, that can make a breakthrough in the design of a solution to a particular problem. The class helps students learn how to approach problems for which they do not have enough background knowledge (and may not even know yet how to acquire enough background knowledge), and it enables students to start seeing their own true potential as learners and researchers. This can be especially important during what can be a tough year.

During the first few meetings of Mission, the class is given a brief introduction to the topic via some key readings and a few brief lectures. On the first day, the students are given clear instructions on deliverables and deadlines and are told about the resources available to them, including the library staff, teaching assistants, undergraduate teaching fellows, and alumni mentors. Within the first week or so, a number of possible subtopics are proposed, and the students break into groups of 5–10, depending on their interests. This facilitates breaking down the problem, as the students must work closely within and between groups. Although a faculty member suggests the initial group topics, the students are free to recast groups as they wish, and they do. Students are also free to refocus or redefine the theme problem as they see fit.

The halfway point of the class can be disconcerting, as our teaching philosophy is to be as hands-off as possible. Thus, as the pressure from other classes that have regular, formal assignments builds on the students, they find that they are way behind in the Mission class, and that leads to some degree of demoralization. We attempt to head some of this off in the first month by giving them what has been termed a "mini project." This is usually some small part of the overall project that each team must work on, presenting a short "solution" to the rest of the class; it serves as an eye-opener, showing the students the level of teamwork and effort that will be required for the final project. Nonetheless, our approach of allowing the students to discover that they are indeed in charge of their own destiny can be nerve wracking at times (for them and for us).

Within that demoralization, though, we also see the beginnings of organization, as leaders begin to emerge both in groups and for the whole class. The three formal class meetings a week are purposely unstructured, and they tend to be spent by students meeting either as individual teams or in whole-class discussions. The leadership of particular students is often short-lived—the class responds to some potential leaders by replacing them as new ones step up. Within a few weeks, there are usually three to five students with whom the rest of the class is comfortable and who can lead discussions. We encourage everyone to speak up, and even the shyest of students might find themselves addressing the class somewhat regularly.

5 Deliverables

The formal requirements for the class are (1) to produce a comprehensive website that outlines the problem and how the students propose to solve it, and (2) to make a formal public presentation before a panel of experts. The websites are not updated after completion, but they live on the web, and we receive many inquiries from students and professionals at other institutions who have run across previous years' websites. For the public presentation, three or four experts are chosen to listen to a 90-min presentation by the students and then ask questions. Without fail, the students do an excellent job of presenting the problem and their solution with slides and well-rehearsed presentations. These are both webcast and archived on our website. The students understand that people from around the world are watching, and they rise to the occasion. Following the presentation a "Q and A" team stands at the front of the room and answers questions, both from panelists and from the audience. For the instructors and the examiners, as much as for the students, this is when we realize the depth and breadth of their understanding of the problem. The examiners do not hold back, but rather explore the students' knowledge in real detail. In general the students do very well, and we repeatedly hear panelists and audience members say they cannot believe the students are only freshmen.

The students understand that the websites will live on the web indefinitely and take great pride in assembling them. In general, the sites are packed with information and ideas, and, as mentioned above, the global audience that communicates with us uses them as a primary source of information and a starting point for deeper research. The students learn a great deal about how to communicate complex ideas via a website, and most find the experience very useful for the rest of their time at MIT and beyond. Examples of two topics with websites developed by Mission students outlining detailed information on their plans can be found here:

Mission 2013 (2009–2010): "Propose a global solution to the rapid rise in atmospheric CO_2." http://igutek.scripts.mit.edu/terrascope/

Video of the final presentation: http://amps-webflash.amps.ms.mit.edu/public/mission-2013/

Mission 2014(2010–2011): "Design a plan to produce and distribute enough food to feed the planet for the next century." http://12.000.scripts.mit.edu/mission2014/

Video of the final presentation: http://amps-web.amps.ms.mit.edu/public/mission2014/

6 Grading

The fall semester for MIT freshmen is graded on the Pass/No Record system, in which a passing grade of any kind is recorded as a "pass" and a failing grade does not appear on the student's transcript. However, "hidden" letter grades are in fact assigned (and revealed to the students), even if they do not appear on transcripts and are not used in calculating GPAs. Although the grades are hidden, most of the students are competitive enough to want to excel. By the end of the semester, the UTFs and instructors know the students well enough to assign grades based on quality and amount of effort.

7 Spring Semester

During the spring semester, we offer two optional classes and an optional field trip over spring break. Enrollments generally drop from fall to spring semester (particularly since Mission is a prerequisite for both spring classes, and so no new students enter the stream midyear), but there is always a core of dedicated students who feel empowered and energized by Mission and wish to build on the experience.

The primary spring class is 1.016, in which the students are presented with a number of research projects that are related to the overall theme of the class. Students identify the projects they are most interested in and are formed into teams overseen and mentored by faculty and staff from across the Institute. The team size can range from as few as two to as many as six or seven. The kind of research can vary from theoretical work to hands-on design and fabrication.

The teaching philosophy is very much the same as in the Mission class and reinforces the team-building and project-management skills students have learned in the fall. The primary differences are that in the spring students turn from thinking about the problem as a whole to particular, detailed solutions, and that they do so under the guidance of faculty conducting active research in the area. However, they are still given a great deal of autonomy in determining the course of their research and the nature of the solution they develop. The skills they have acquired in the fall enable them to start immediately breaking down the problem and planning their research. Once again the philosophy is to treat them as scientists and engineers, not as freshmen, and to encourage them to take charge of their own learning. Among the learning goals of Subject 1.016 are: to give students the opportunity to exercise and reinforce the team-building, communication, and research skills they developed in the fall; to give them practical, hands-on experience to complement the broader, more theoretical work of Mission; to provide them with research and/or design experience, in which they will have the opportunity, as freshmen, to work closely with faculty and other investigators; and to continue to develop communication skills both within the class and with the broader community.

The deliverable of this class is a “Bazaar of Ideas,” in which each team builds and equips its own bazaar-style booth, filled with models, demonstrations, prototypes, text and graphic panels, and other means of communicating their work and results. The bazaar is open to members of the public, who go from booth to booth, learning from students’ presentations and asking detailed questions. In addition, a panel of experts is recruited to visit all of the booths in sequence, and each team of students has between 10 and 15 min to present its semester’s worth of research and to answer the panelists’ questions. The next day, panelists visit the classroom, critique the students’ work, and engage in dialogue with the students. The students care deeply about the panelists’ evaluation of their work, and, thus, this final presentation provides them with a strong mix of tension and (ultimately) pride in their accomplishments.

Although students in 1.016 now understand the value of timelines and communication within a team, there is still quite a bit of floundering, particularly early in the semester. As teams become engrossed in their own projects, there are multiple milestone occasions on which the class meets as a whole to compare progress, give one another suggestions, etc. One additional objective of this process is to maintain the strong community spirit within the class. The class also emphasizes the role of reflection in project-centered learning. Every week, each student writes a short, reflective journal entry on his or her experience in the class that week. Students write candidly about their joys and frustrations in the class, and instructors comment promptly on these reflections, often establishing a running dialogue with individual students. Grading is based half on team accomplishments (proposals, progress reports, and of course the final bazaar booth and presentation) and half on individual work (journal entries and effort/quality of work on the project, as assessed by instructors and UTFs).

Examples of projects in 1.016 have included traditional research and development projects (e.g., a passive-solar crop-drying apparatus for farmers in developing countries; a proof-of-concept model of a gravity/pressure-based mechanism for storing energy collected by ocean-based wind turbines; new, less greenhouse-intensive formulations of concrete) as well as projects more focused on outreach, public education, and development (e.g., a multiplayer game that focuses on the trade-offs inherent in preserving biodiversity while encouraging economic development; an SMS-based system for improving the efficiency of healthcare provided by traveling nurses in rural areas; an interactive museum exhibit on the diversity of microbial life). In their bazaar presentations, students have shown strong engagement with the problems and projects and an impressive ability to communicate the essence of their work—as well as its limitations—both to the general public and to the panel of specialists.

The other spring class, Terrascope Radio, also builds on students' experience in Mission, both in terms of content and in terms of team building, group work, project management, and related areas. In this class, students focus on communicating their knowledge and opinions to nontechnical audiences, a skill that is often underemphasized in a technical education. In particular, students are asked to develop the ability to understand the needs and interests of general audiences and to acquire a sense of how to serve those needs and interests. During the course of the semester, the students also develop a strong appreciation of the broader societal context in which their scientific and technical work will take place, they continue to build their sense of their own deep potential as learners and creators, and they acquire a deeper understanding of the year's theme problem, all while continuing to take responsibility for their own learning.

The final project of the class is a 20–30-min radio program, which is played on the MIT radio station and then made available for licensing by public and community stations around the country. (Nearly every Terrascope Radio program has been licensed by at least a few stations, and some have been broadcast widely.) Students are free to choose the format, content, and style of their program. Examples of previous years' programs can be found at http://web.mit.edu/terrascope/www/radio_archive.html.

Radio is a linear medium—audiences cannot skip forward if they are bored or skip backward to be reminded of an earlier part of a program. Hence, in order to be successful, students need to learn how to get and hold the attention of their audience. To do that, they need to build a "toolbox" of techniques and approaches. To that end, roughly half of class time in the first 2 months or so of the semester is devoted to analytical listening and discussion of a wide variety of radio/audio pieces. The other half is devoted to hands-on work, in which students learn how to operate sound-gathering and editing equipment, how to conduct good interviews, how to find appropriate sound, how to listen carefully to their immediate environment, and how to pull everything together into a produced radio piece. For the last month or so of the semester, students focus almost exclusively on working in teams to create their final project. More details on the nature of the class, and on outcomes for students, can be found in Epstein et al. (2010).

In Terrascope Radio, final projects have ranged from traditional documentary-style programs to personal reflection and commentary to radio drama, and they have also included hybrids of the documentary and radio-drama formats. In all cases, students have shown a strong understanding of what it takes to engage listeners and maintain their attention while imparting complex scientific and technical information, and they have developed skills in both the technical aspects of audio production (e.g., editing, mixing, sound gathering, interviewing) and the techniques of audio-based storytelling. One issue that is faced by every class involves the trade-off between conveying information directly (as in a documentary) or indirectly (as in a personal reflection or a character-based drama). A significant number of students have continued to work in science-based audio production and outreach after taking the class.

8 Spring Break Field Trip

An exciting part of the program is when students have the opportunity to see what the problem is like on the ground and to get a sense of the potential for their proposed solutions' effectiveness. Overall, the trip solidifies the community of Terrascope students, faculty, and staff and provides the group with a unifying experience. In many cases, the travel is international; in recent years we have gone to India, Abu Dhabi, and Costa Rica. These trips are expensive, and the costs are borne by a combination of the students and foundation support that we have been fortunate to obtain over the past decade.

A main objective of the trip is for the students to experience new cultures but in the context of doing science and engineering. With travel, the actual time on the ground is usually 5 or 6 days and requires a great deal of planning to maximize the learning experience. We typically work out itineraries with local experts from universities, government agencies, and the general population. Our goal is an intense learning experience that includes hands-on activities, lectures, and "Q and A." The students are very curious and often ask such detailed and informed questions that hosts expecting "freshmen" are a little surprised. The field trip provides both reinforcement (some of the students' proposed solutions are very much on target) and caution about pitfalls of attempting to solve problems without understanding local situations in detail. It is one thing to have plans to relocate people or transition them out of their traditional line of work, and another to have to explain it to the people. On every trip we have unexpected interactions with local people; many love to talk and are excited, and often amused, that students from a major university would come to their region. We are flexible enough to accommodate students who wish to talk at length with these people, from radio interviews to sharing a meal. These unplanned interactions add a great deal to the overall experience and again emphasize that the students can, to some degree, control their own education.

Perhaps one of the best ways to get a feeling for the importance of the field trip is to read students' blogs associated with two recent trips:

To Abu Dhabi (http://mission2013trip.typepad.com/)
And to Sirsi, India (http://mission2014trip.blogspot.com/)

Although the field trip is part of the Terrascope program, it is not an essential component of the overall educational experience. The most important part of the field experience is that the students spend a week together learning, and this can be accomplished without expensive travel.

9 Outcomes

One outcome of the yearlong Terrascope experience is that groups of students often become so passionate about the problem they have worked on that they form and/or join both formal and informal groups focused on their problem. There are many opportunities for students to get involved in further research, both at MIT and abroad, and many students take advantage of these, especially opportunities that allow work in another country. In the spring class, many have been eager to continue working on their specific projects after the end of the semester. More than half of the project teams have continued in some fashion, with some students going on to present their work at professional meetings, others obtaining grants or fellowships to continue their work abroad, and others employed in summer or semester jobs.

In addition to the formal evaluations mentioned above, a number of other, more anecdotal elements have provided us with good insight into the program's effectiveness. For example, one of us (A.W. Epstein) co-teaches a sophomore-level CEE class that focuses on design and fabrication in team settings, and he and his colleagues have found that they have to place former Terrascope students on separate teams, since teams that include multiple Terrascope members have a distinct advantage over other teams in their ability to attack open-ended problems, establish appropriate process, and communicate among team members. Other information comes from talking to students who have graduated. They emphasize that the skills they developed as freshmen served them well throughout their time at MIT, during the job interview stage, and in graduate school and/or the work force.

One of the best ways to gauge the effect of Terrascope on students is to read and listen to what they have to say about it themselves. A number of students were asked to talk about Terrascope, and videos of their responses are posted here:

http://web.mit.edu/terrascope/www/videos.html

Below are typical comments from the past decade, some of them recorded during video interviews and others extracted from formal evaluations or group discussions.

> What the whole Terrascope program taught me was that you have no limitations. Or you might have certain limitations, but you don't know what they are yet, and [the program staff] stretched everybody.
>
> Even though you may not have the correct background, even though you may not have all the skills that you need, you know that here you can get all those skills.
>
> When people disagree, you learn how to resolve those problems in a diplomatic way, and those are really valuable skills, and this program gives you the opportunity again, and again, and again to deal with that.
>
> Having professors willing to step back and let you take the reins and do what you think is best is an incredible feeling, and it's an exciting opportunity to have during your freshman year.
>
> I realized that I could solve a big problem. Whereas before it just seemed like it was so impossible. But after the class I realized that if you could break it down into these little parts, and you each do your thing, then you actually come up with a good solution.
>
> That's what Terrascope gave me. It gave me the ability to believe in myself, that I can change the world, that anything that I have a passion for, I have the ability to change.
>
> My best friends are in Terrascope, and I know many more faculty members (and they know me) than most other freshmen do, and this has opened many doors during this year.

10 Discussion

The Terrascope program provides a unique opportunity to teach students about the Earth system and the role humans have had in modifying it. It combines basic geoscience education with research-based projects that involve teamwork and a strongly interdisciplinary approach. The students develop skills and an approach to their own education that serves them throughout their undergraduate degree and then in graduate school and/or in whatever jobs they end of taking. We believe that basic geoscience education is as important as physics, chemistry, and math, and through Terrascope the students develop a broad appreciation of geoscience, environmental science, and sustainability, giving them skills and knowledge that will enable them to be better global citizens.

We believe that similar programs could be implemented at a wide variety of institutions, serving many kinds of students. For those who wish to do so, we offer a few suggestions based on our experience over the past decade. The first is to be willing to step out of one's own comfort zone. Most instructors will be unfamiliar—and likely uncomfortable—with this nontraditional approach; one really needs to experience an entire semester of such a class in order to get a sense of its potential. (We note that this is true for students as well as faculty.) It can be difficult to tell until the end of the semester whether the class is going to be a success or a failure—things are chaotic, and students' success depends on undergoing an extended period of frustration and apparent unfocussed work. Very often things do not come together until nearly the last minute, and that can be discouraging for inexperienced instructors. Second, classes like those in the Terrascope program generally require more resources—space and staff/faculty time—than traditional classes do and so can be more expensive on a "per credit hour" basis. Third, programs like Terrascope work best when students want to be in them and commit to them; the community-based elements of the program do a lot to support students' continued involvement, engagement, and comfort. The field trip component we have developed is a great experience for all, but it is not essential to the program's educational mission or success.

Overview

Status Quo and/or Trends

– Freshmen in science and engineering are often told that they must take basic classes before they can take on original, challenging projects.
– Traditional coursework consists largely of lectures, assignments, and tests, even though most students' eventual work will involve open-ended, unstructured problem solving. College-level work often focuses on individual accomplishment within particular disciplines, even though professional work often requires the ability to function in multidisciplinary teams.
– Students with science or engineering degrees often have little skill in communicating with nontechnical audiences, political bodies, etc., even though those skills are becoming more crucial.
– There is, however, a strong trend now toward more team-oriented, project-based learning.

Challenges to Overcome

– High-performing students often have great ability to carry out set tasks, but less ability to take control of their own process and little willingness to step outside their comfort zones.
– Teaching classes as described here requires different skills and attitudes—less emphasis on formal teaching skills, and more on ability to establish an environment in which students have autonomy and support in their own learning.
– Project-based, team-oriented classes require a greater commitment of staff time and institutional space than traditional classes.

Recommendations for Good Practices

– Treat students as researchers capable of framing and tackling problems on their own. Make this an implicit, unstated but constant expectation. Empower students to take ownership of problems and processes; this requires flexibility in defining the outcome of students' work.

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- Engage a wide variety of personnel. Older undergraduates provide a unique style of support; alumni are effective role models and sources of information. Students also benefit from learning that there is much help available from librarians and technical staff.
- Provide high-stakes, public presentations at the end of each semester; students often care more about impressing outside experts than their everyday instructors, and the desire to excel in front of a public audience can provide better motivation than grades.
- Our approach is scalable: A Mission style class could be run for a week or more or half a term. There is no need to start with a fully developed year-long or semester program.

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Students' Final Projects: An Opportunity to Link Research and Teaching

Dolores Pereira and Luis Neves

1 Introduction

Spanish universities are finally involved in the process of reflection and reorientation of the studies to promote a qualitative change in the educational university model, as other European universities have been doing for several years now. According to the European Higher Education Area (EHEA) study programmes, students have to present a final project at the end of their bachelor degrees (de la Cámara Delgado and Saenz Marcilla 2010). This could be an opportunity for these undergraduate students to participate in academic research. In 2007, a Spanish Royal Decree established the planning of higher education in Spain, contemplating the need to include general and specific qualification competences in university studies. In the case of the degree in geological engineering, such competences can be described as follows (Fig. 1):

– Instrumental, technical competences: cognitive skills, methodological skills, technological skills and linguistic skills
– Interpersonal, generic competences: individual competences such as social skills (social interaction and cooperation)
– Systemic competences: abilities and skills concerning whole systems (a combination of understanding and knowledge, prior acquisition of instrumental and interpersonal competences required)

The process in Portugal was carried out earlier, with the degrees adapted to the Bologna format at the University of Coimbra starting in 2007/2008. The same competences described above have presided over this important change in the Portuguese University degrees.

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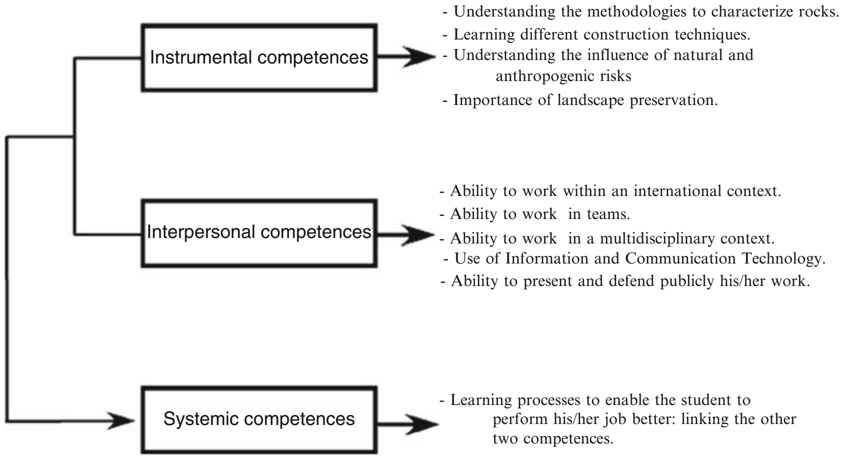

Fig. 1 Competences to be developed by the students in the EHEA

The research group known as "Characterization of Geomaterials" at the University of Salamanca is composed of researchers from that University, the University of Coimbra (Portugal) and the Spanish Geological Survey. This research group was created in 2005 and since then it has been growing both in members and in interdisciplinary contents. Most of its components belong to the Earth Sciences Departments of these institutions, and different areas are covered: petrology, geochemistry, geomorphology, mining, geotechnical characterisation, natural risks and geological engineering. The research group investigation lines go from basic science to applied science in different fields: environment, restoration, construction, etc. Teaching research methods to undergraduates presents several problems, one of them being to provide students with research subjects (Winn 1995). One way of addressing this issue, and indeed others, is to enable students to participate in a real research project, and this can readily be achieved if the students are incorporated within a research group. The advantage of being involved within an international and multidisciplinary group such as ours is to allow students to combine the different areas of knowledge acquired through their degrees to obtain a broader view of science in general and to put into practice the competences promoted by the EHEA (De los Ríos et al. 2010). Moreover, since our research group is also involved in international educational projects (e.g. the ERASMUS Intensive Programme "Global Heritage and Sustainability: Geological, Cultural and Historical"), our students can enjoy an international atmosphere, spending some time at other European institutions.

The authors of this book chapter have been working together on the tutoring of students of geological engineering from the University of Salamanca, combining their expertise in both the teaching of engineers and teaching in an already adapted system, as is the case at the University of Coimbra. Geological engineering at the University of Salamanca includes a final project as mandatory to finish the degree, the same as for the Bologna-adapted system, except that its value is only of 6 ECTS credits, in contrast to the 12 ECTS credits in the adapted system. Our experience has served to prepare the schedule for the other degrees we are involved with, since all of them include a final project. In this contribution, we highlight the relationship between teaching and research, but we also state the difficulties that the teaching staff may encounter deriving from the passive way of learning that the students have been following so far and the complications they find once they have to face their own project to obtain the results to conclude their final project.

2 Motivation and Rationale of the Project

The European Higher Education Area (EHEA) has introduced some changes in student curricula that will prepare their promotion within European citizen employability and the international competitiveness of the system. The Bologna Declaration (1999) marks a turning point in the development of European higher education and competitiveness in Europe. Students will now have to complete a first cycle that will be relevant to the European labour market as an appropriate level of qualification or if they wish to start a second cycle within the EHEA. One of these changes is related to the completion of a final project. This final project can be defined as an assignment completed by the student during the last academic year of the first cycle, and its purpose is to assess the student's general competences in the subject of the degree course. The final project must carry between 6 and 30 ECTS credits.

The idea of a final project to complete the first cycle was already implemented in engineering studies in Spanish universities (Montes et al. 2007), although credits would differ in the different subjects and in the different universities. The geological engineering studies at the University of Salamanca have a six-credit final work project within its programme in the current non-adapted studies, which will become a 12 ECTS credit mandatory part in the new, adapted system. Geological engineering studies have a duration of 5 years in non-adapted degrees, but have become 4 years with the new Bologna system (Fig. 2).

In non-adapted studies, the degree obtained is called "geological engineering". In the latter, the degree is called "graduate in geological engineering". The non-adapted degrees will end in 3 years from now (2013–2014 will be the last academic year for its implementation). Therefore, we still have to facilitate the development of work projects to three more academic years before starting with the new system. At that point, the work project will be called the final project. To avoid confusion, henceforth we will refer from now on only to "final project" to describe our experience.

In the adapted system, the final project will be awarded 12 ECTS credits instead of 6 and if a project is related to an already ongoing research line, it is easier to adapt it.

The new degree in geology under the Bologna format started in the University of Coimbra in 2007/2008, with a duration of 3 years, followed by a master's degree with 2 years (formerly 4 + 2 years). In the case of geological engineering

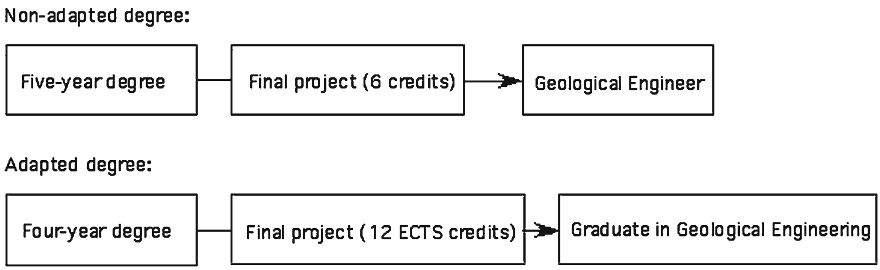

Fig. 2 Comparison between adapted and non-adapted geological engineering studies in terms of total duration, final project duration and degree obtained

and mining, the first cycle is now common with civil engineering (3 years), with a second cycle of 2 years (formerly 5 + 2 years). Only in the case of the degree in geology has a final project, with a total of 6 ECTS credits, been kept in the second semester of the third year.

Because of the lack of experience in the engineering geology studies at the University of Salamanca, final projects are often misunderstood by the teachers as real research projects, and they may take students a fairly long time to complete, so demanding an extra effort to the students relatively to the credits conceded. It is our duty to give our students a project that can be easily concluded during the time established to complete the project credits (corresponding 1 credit = 10 h in the non-adapted studies; 1 ECTS credit = 25 h in the adapted studies). The achievement of a timely finish of these projects may require a change of culture amongst both students and teaching staff. It is an important task for study administrators to inspire and follow up on the culture change.

For students to start their final project, they are required to have passed the other subjects of the degree to be considered their inscriptions. The project may be linked to all the different areas of knowledge that have been taught during the degree, both in Spain and Portugal. Regulations state that a final project can be adapted to a professional or a more research-oriented work. During the project, students will have to show how they apply their knowledge, skills and abilities in one or more subjects taken during their career.

3 Description of the Experience

Geological engineering studies were established at the University of Salamanca in 2000. This university is the only one offering this course, together with geology, in all Castilla and Leon region. Even under this circumstance, very few students follow this degree, around 20 students entering every year. It is possible that this situation derives from the current economic crisis that has cut many job options related to this type of training. Most of the teaching staff are geologists and few engineers

Table 1 Students with research-oriented final projects, some already defended

Student	State of the final project	Title of the final project
Carlos	Defended October 2008	Natural radioactivity in construction materials
Cristina	Defended March 2011	Geochemistry of a soil developed in the surroundings of a mine: the case of Barruecopardo
Gerardo	Defended March 2011	Chemical composition of a soil in the proximities of a main road: anthropogenic influences
Francisco	Defended September 2011	Granite weathering profile: applications in industry
Marta	Defended September 2011	Environmental implications associated with an urban waste dump. The case of Villamayor
María	Defended September 2011	Radiological study of ornamental stones from Castilla and Leon
Lidia	Defended September 2012	CO_2 sequestering proposal through the carbonation of serpentinites
Irene	Defended July 2012	GLOGE: a multidisciplinary study of global heritage
Ana Belén	In progress	Red granites and their behaviour as ornamental stones. Spanish and European examples
Leticia	In progress	The blue granites of Plasenzuela
Remedios	Defended July 2012	Geological evidences in the study of the mineralisation of Cotovio sector, Neves Corvo mine, Portugal
Ana	Defended March 2013	Radiological characterization of Rojo Sayago episienite

participate in the teaching, most of the latter being invited lecturers who do not belong to the regular departmental staff. In Spain, the economic crisis has mainly affected the construction sector.

The common teaching practice of our research group "Characterization of Geomaterials" is to include real examples coming from our own research in our lectures. This facilitates students' awareness of the applications of science to real cases and fosters their curiosity about the different subjects that have been taught during the previous years. The final project is a perfect opportunity for these undergraduate students to participate in academic research activities.

Table 1 shows the projects that have been defended (González-Neila 2008; Calvo 2011; Espinosa 2011; Arce 2011; Septién 2011; Manteca 2011; Olmos 2012; Ferrero 2013) and the projects that are about to be completed or still under way. Taking into account that the degree in earth sciences is not an excessively pupil-crowded study programme, this student involvement can be considered a great success. The research group was created in 2005 and that was the first year that geological engineering students had to start their final projects (recall that the Bologna non-adapted studies are still 5 years long for engineering). All projects we have tutored or are tutoring are related to the research lines of the group, the expenses being covered by the funded projects of the same research group. The results of three of these projects have been presented at international congresses; two are part of international journal publications (Pereira et al. 2011, 2012) and others are parts of papers in preparation. The undergraduate students form part of the authorship of the research products, which is a new experience for them since they are responsible for the results coming out of teamwork, and this experience shows them that research and teaching can be combined very successfully.

Surveys carried out on the students have shown that it is far more interesting for them to work with real data than to learn only through the traditional method of following very theoretical classes. However, we have encountered serious problems when dealing with students who are not used to working autonomously, taking decisions and generating results on their own.

Lectures in the non-adapted system have traditionally followed the so-called magister class, in which the teacher explains the lesson and the students literally write down what he or she says, with not much interaction between either party. Thus, when the students reach their final year and they have to confront a final project with the characteristics we offer, they have difficulty in applying the knowledge gained previously; they are very dependent on us, and this situation leads us to spend too much time on setting the students to work at the cost of other responsibilities (i.e. research and management duties). So far, we have managed the situation quite positively, but it should be taken into account when admitting more final projects before the completion of the non-adapted system. It is academically assumed that the adapted system should prepare our students for greater focus on practical work based on personal efforts.

4 The Final Project: A Professional Exercise or a Career Subject?

Engineering and architecture studies have been using traditionally the term of "final project" as an exercise to integrate or synthesise the training the students have received throughout their studies. In this project, students must demonstrate their skills and competences by integrating them with the knowledge gained in the qualification. However, for most students, the scope of the final project is to earn the final certificate of the studies and to start looking for a job. Therefore, students can face the final project just like another subject they have to pass. Our aim as teaching professionals and researchers is to offer them the option of becoming involved in a project as though they were fully fledged members of the team (Lucas and Roth 1996).

Students normally decide about the subject matter of their final project when they are in their fourth year of university studies. There are two options for the choice of a research topic:

1. The teaching staff publicly offer a set of topics to the students.
2. The students choose a tutor who will offer them a theme.

The first option looks for the student's ability to apply the knowledge, techniques and abilities gained during the teaching of one or several subjects. The second option currently seems to be the most favoured, firstly because the tutoring of final

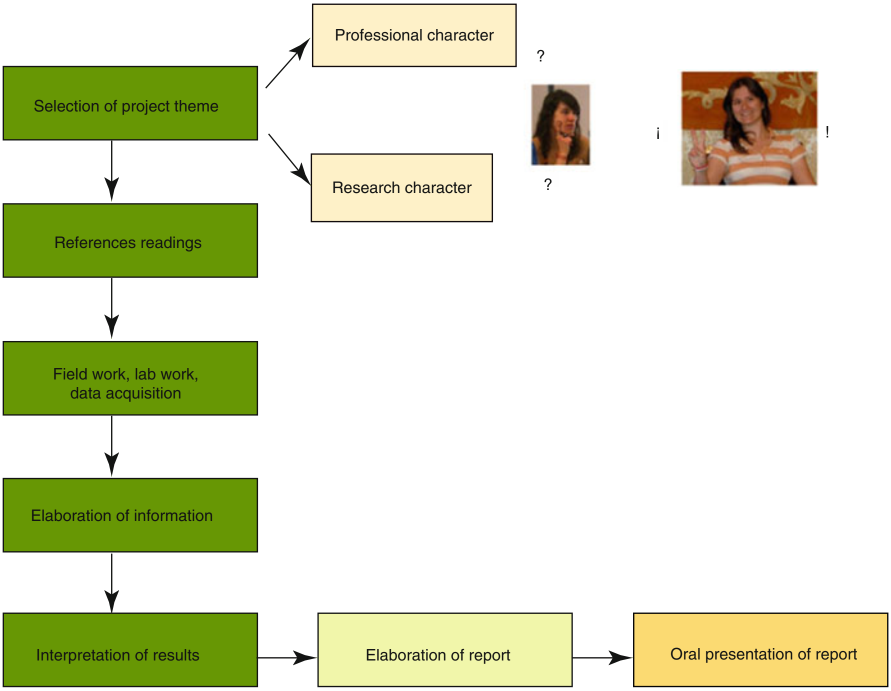

Fig. 3 Evolution of the final project. Maria had to decide whether to choose a more practically based project or a research-oriented project. Irene had it clear from the beginning

projects is not mandatory for the teaching in the non-adapted degrees and secondly because in a degree with few students, as is the case of geological engineering, the students have already decided on their preferences as regards working with certain members of the staff. However, for some of the staff, this situation is now leading to an overload of final projects to be tutored, and, although it is very rewarding personally, it increases the teaching dedication of such instructors substantially, to the detriment of their research activities.

Once students have decided on the project or the tutor who is to supervise their projects, a decision must be taken: Should the students become involved in a professionally focused project or in a research-focused project? (Fig. 3)

This will depend on both the student and the tutor. In a degree course that seems to be of practical nature, one would suspect that students would prefer to choose a more professionally oriented final project. However, we have observed that many students decide to choose a more research-oriented final project.

Another observation is that more female students decide to choose a research-oriented final project in comparison with their male peers. When discussing this with them, they have commented that the studies they have followed do not fulfil their expectations and in the end, they try to become involved in something different. We have noticed that students spend more time than expected following this degree (although this is also the case of many others). In the event of the students finishing their 5-year degree (three in Portugal), they stay for at least two or three more than expected. Some students even leave their studies for some time, finding temporary work, before going back to finish their degrees, which include the final project. Other students begin their final project without passing in the previous subjects before presenting their project. This latter case, although rare, shows that they are not very particularly happy with the courses they are following and prefer to spend some time doing something different. This anomalous behaviour and its consequences can be related to a failure in the students' expectations either because their vocation was mistaken or because the study plans are not amenable to them. This observation deserves further study, and it should be addressed separately elsewhere.

5 Use of Information and Communication Technology in Final Project Management

The implementation of the final projects proposed by our own group has been facilitated by the use of the new information and communication technologies such as the USAL virtual campus (Figs. 4, 5 and 6). Through this portal, we can communicate amongst ourselves (i.e. professors and students), exchanging ideas and material between tutors and the students. It should be noted that information and

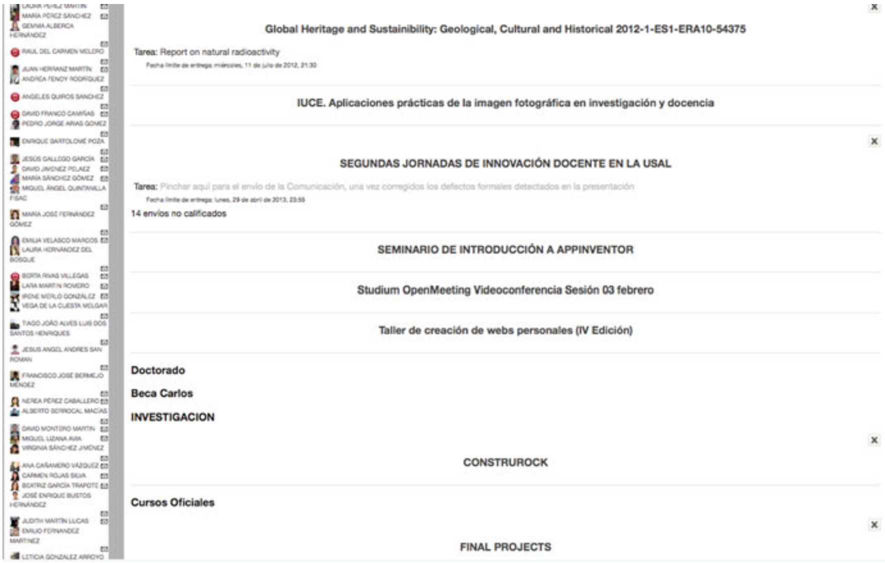

Fig. 4 First page of "Studium" for the subjects taught by D. Pereira at the University of Salamanca. The final project is presented like other official subjects within the study programme

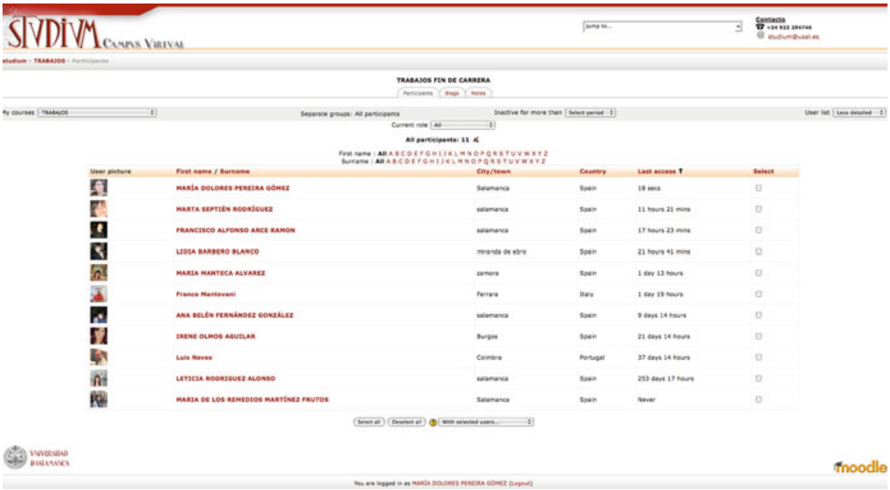

Fig. 5 Moodle page showing teaching staff and students that have just finished or are participating in ongoing final projects

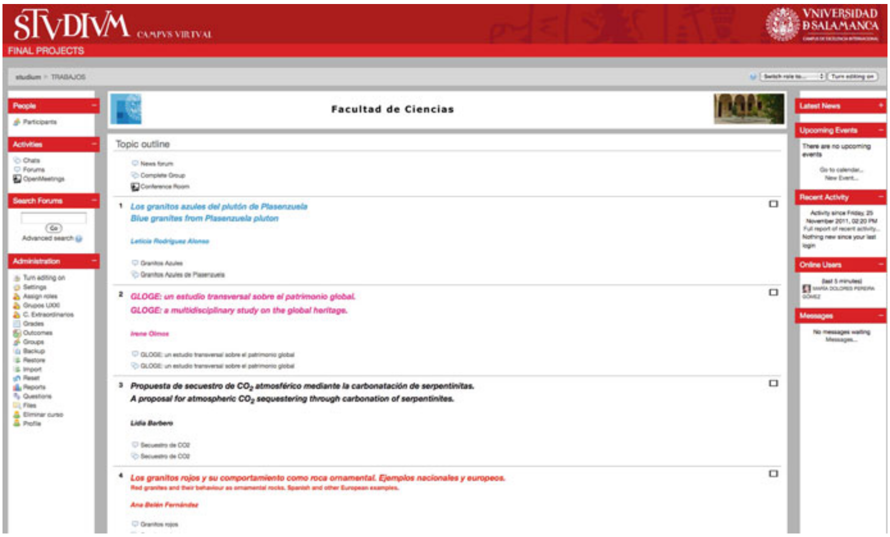

Fig. 6 Virtual platform with present students and their final project spaces

communication technologies can help in teaching, but they will never replace the personal exchange and interaction between students and their tutors. Despite this, in the final project, there are more advantages than the disadvantages that some authors have encountered in teaching-learning experiences (Beauchamp and Kennewell 2008; Kennewell et al. 2008).

The virtual platform at the University of Salamanca, called Studium, is based on Moodle (Modular Object-Oriented Dynamic Learning Environment), a free source e-learning software, and it allows all participants to remain in touch through forums and chats, to upload all the documentation that the students may need for their personal research. A sequence of versions of the projects are uploaded by the students for their comments and corrections until the final one is achieved. This e-learning system is used for all the different subjects under the responsibility of the tutors at the University of Salamanca, and, hence, all students following their final project with us are familiar with Moodle. Figure 4 shows a list of the courses taught with the help of the information and communication technologies, and all of them included in the virtual campus at the University of Salamanca. “Final projects” are contemplated in Fig. 4 as another official subject of the course. On the virtual campus, the activity of the participants at any moment may also be seen. This helps the supervisor to control the degree of involvement of a particular case (Fig. 5). The platform offers the possibility of retrieving an activity report for each student. In the case of the final project, such activity reports are not that important because most activities are performed through the forum, but for the other subjects, where the final marking is based on on-site activities and the virtual activities performed by the students, it is very helpful.

It should be noted that the final project regulation states that the product of a final project is the property of the author and the tutor or team group where the project was developed. Because the projects we are tutoring are funded with public money, coming from competitive public tenders, once they have decided to work with us, we make it clear to the students that the results will be made public and available in open access: first at the university repository and then as publications. So far, we have not had any complaints about this, and indeed some of our students find the system useful when they apply for a job and this is almost the only extra achievement they have once they have completed their degree.

Once the students have defended their projects, their space is deleted from the virtual campus and their complete presentations are uploaded to the USAL repository, which has open access and thus promotes the exposure of their results (Fig. 7).

6 Outcome of the Project

The goal of this project has been the integration of final-year students in the research team for at least a whole year. During the research and preparation of their projects, the students become involved in the atmosphere of the field of research and some of them decide to continue investigating in the same or a similar area of their project. Final projects are now replacing what were formerly known as “dissertations” since the latter are not readily recognised in the new adapted study plan. Although most final projects completed so far at the university are related to applied science (i.e. geological engineering), many students decide to choose a subject related to research issues.

Fig. 7 Online publication of the final projects defended in the USAL repository

The final projects we have tutored follow part of the research lines of funded projects and hence all the expenses regarding analyses and others were covered. Some of the projects used data from earlier research proposals that were never published. This was the case of Cristina's, Marta's and Gerardo's projects. The three of them worked with data from the analytical study of soils to discern the implications of anthropogenic influence. Once defended, Gerardo found a training job with an engineering company. Cristina has presented her results at an international congress of geochemistry in Portugal (Espinosa and Pereira 2011). Carlos began his final project when the research group started to work on natural radioactivity related to ornamental rocks. After defending his final project, Carlos helped to prepare a communication that was presented at the International Geological Congress held in Oslo in 2008 (Pereira et al. 2011). Currently, he is a researcher with us, funded by the Heritage Foundation of Castilla y Leon. This means that although he graduated in a very applied subject, he is happy working in basic research lines and that we have succeeded in organising the best conditions possible for such endeavours in our research group.

All the defended projects commented above and the projects that are currently under preparation have the typical methodology of a research project, i.e. finding related references, performing fieldwork (Fig. 8), laboratory work (Fig. 9) and some office work with statistics, graph plotting and data processing.

Fig. 8 Fieldwork involved in the project. Carlos is accompanied by several members of the research group to collect samples for his final project. His project was co-tutored by the co-authors of the present work

Fig. 9 Laboratory work involved in the project. Marta weighing her samples for her final project. Her project is co-tutored by the co-authors of the present work

7 Conclusions

After tutoring several research-based final projects, we arrive at the following conclusions:

During the elaboration of the final projects, both teachers and students assume an active role. Students have demonstrated their commitment and responsibility for their own learning. However, this situation is somewhat difficult for the students since they are not used to working on their own in the non-adapted system. It is an extra task for the tutor to convince them that our own role is simply one of tutoring: it is they who must fulfil the active part of the bargain. As the adapted system contemplates as an objective to prepare the students on competences, this will lead (hopefully) the student to a more independently work on the final project.

Personal competences that were not emphasised in the previous academic years are also developed. Students learn to work in teams, since some topics are common to several of them (geochemistry, characterisation of natural rocks for construction, natural radioactivity, etc.). The methodology used arouses in the students a spirit of investigation, discussion and innovation, creativity for the generation of new knowledge, productive thought, and the motivation to learn and solve problems on their own (Ryder and Leach 1999).

During our experience, research and teaching have been clearly related. To apply the methodology, research grants to the tutors have been essential, allowing the use of investigative material for students' projects.

To conclude, the present experience has been implemented in final-year geological engineering students. Although the project topics we offer are very scientifically based and they do not have straightforward applications in certain fields of engineering, many students choose them. Teaching these students has shown us that they value their consideration as part of a research team, and, with their help, research and teaching are readily linked. Nevertheless, the embracing of students as part of a team takes quite a long time since they are not fully aware of their own learning capacities and seem to be highly dependent on their tutors. We believe that once the adapted system is up and running, and also in view of its own philosophy (working the different competences in parallel), the role of tutors will merely be to support and guide our students, with them spearheading their own research tasks.

Our group has also been involved in teaching and educational projects. In 2010, the ERASMUS Intensive Programme (IP): Global Heritage and Sustainability: Geological, Cultural and Historical (GLOGE 2010-1-ES1-ERA10-22325) was approved, the University of Salamanca being the coordinator of the programme and the universities of Ferrara (Italy), Coimbra (Portugal) and Budapest (Hungary) being the partners in the programme. The IP has afforded students and teaching staff the opportunity of exchange and more final projects have derived from this situation (Olmos 2012). The advantage of being involved in an international and multidisciplinary group such as ours is that it allows students to combine the different areas of knowledge acquired in their degree courses in order to gain a broader view of science in general and to put into practice the competences promoted by the EHEA. A second edition of this IP was approved in 2011

Fig. 10 The GLOGE IP course was implemented as well using the Moodle virtual platform

(2011-1-ES1-ERA10-37081, http://campus.usal.es/~globalheritage/, Fig. 10) and it was implemented in July 2012. The third edition will take place in July 2013.

We may conclude from this experience that research and teaching are clearly connected and very much appreciated by both students and instructors. However, we should teach students to work more independently from the very beginning if we are to avoid somewhat hesitant students once they have started their final projects.

Overview

Background and Motivation

– Engineering students in their final year have to present a final project before graduating. This project may be of a professional nature or research oriented. This practice will in the future be mandatory for all adapted studies, following the Bologna declaration.

Innovations and Findings

– Publishing their results in international journals and presenting them at international congresses are new experiences for the students, fostering their motivation to continue their research under our guidance.

(continued)

(continued)

- E-learning platforms enable us to maintain contact with our students and other co-tutors even when working from different parts of the world. It should be noted that information and communication technologies offer good tools for interactivity between students and teachers, although other dialogic and communication methods are also useful for attaining a good level of interactivity in teaching.
- We have encountered a serious problem when dealing with students who are not used to working on their own. A direct consequence of "magister class" lecturing is that our students become very dependent on the instructor.

Implications for Wider Practice

- Our experience of tutoring more than nine final projects in recent years has shown that teamwork is highly motivating for students.
- The tutoring of these students is not expensive, since most of their research is interwoven with research ongoing at our facilities. In any case, it has to be taken into account that the value of the production of a skilful candidate is much larger than the possible extra expenses involved into his/her preparation for the society. Students' involvement in research-oriented final projects enriches the final products.
- We do not believe that our experience can be implemented when dealing with larger groups of students, because such a task is very challenging for individual tutors and, in projects of this type, students need closer management.
- New educational regulations will drastically increase the number of students in need of a topic for their final project. A good idea would be to offer a guide of good practices, where both students and tutors have a clear idea of what to do and what to expect from each other and from the project.

Acknowledgements The authors thank the following funding sources that made it possible for us to carry out the final projects that illustrate our experience to date: SA110A09, CGL2010-18579/BTE and GLOGE 2010-1-ES1-ERA10-22325. They also thank the commitment of the students cited and all the students who year after year wish to become involved in our group for the completion of their final project. Nic Skinner helped us in arranging the English version. Two anonymous reviewers contributed with their suggestions to the improvement of a previous version.

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Teaching Environmental Sciences in an International and Interdisciplinary Framework: From Arid to Alpine Ecosystems in NE Spain

D. Badía, N. Bayfield, A. Cernusca, F. Fillat, and D. Gómez

1 Introduction

There is a growing need to develop, teach, and apply successful problem-solving approaches on environmental sciences and to educate the next generation of scholars and professionals in real-life scenarios (Clark et al. 2011). One of these approaches is interdisciplinary, based on the concept that through broad understanding of sustainability and human-nature interactions, it is possible to produce consistent recommendations on sustainable land use that improve human quality of life (Vincent and Focht 2011). Interdisciplinary environmental education requires that programme curricula include concepts from the natural sciences and applied sciences, as well as socio-economic aspects. For an effective and enjoyable form of teaching and learning, for both staff and students, different learning activities should be used, including field work, lab activities, group discussions, presentations after group work, lectures, assessments, and writing reports. In earth and environmental sciences, one of the most effective learning activities to integrate many theoretical and practical concepts and tools are

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field visits. Field experience is also seen as vital for training students of geology, biology, ecology, or geography, whose careers may be closely related to natural or semi-natural environments (Field et al. 2011).

Using this framework, we have developed an itinerant course, bringing together people from different disciplines and cultures. The course focuses on sustainable development in European rural areas and supplements direct teaching in the field with talks by experts and comparison of opinions of policymakers and stakeholders. In addition, there are debates among the students over different solutions to ecological conflicts at the sites visited and in their respective countries. In this way, the course brings together students of different nationalities in a common European Higher Education Area, complying with the recommendations of the "Bologna Convention" (Anonymous 1999).

2 Motivation and Rationale of the Project

2.1 Background

The educational project originated in 1999, in the framework of a European research project titled ECOMONT (Cernusca et al. 1999) developed under the Terrestrial Ecosystem Research Initiative (TERI) as a contribution to framework IV for research and technological development of the European Union. Nine European partner teams in six composite landscapes in the Eastern Alps, the Swiss Alps, the Scottish highlands, and the Spanish Pyrenees carried out ECOMONT. Taking advantage of this project, a visit with students from the University of Innsbruck (Institut für Ökologie) to the study sites in the Spanish Pyrenees was organised with the aim of showing the students the objectives, methods, and results of the European research project and at the same time comparing some ecological process and socio-economic aspects of the Alps and the Pyrenees mountain ranges, such as rural abandonment (Tappeiner and Cernusca 1993). The field visits were focused on training students in analysing and discussing the differences and similarities between nearby European territories with similar biogeography and ecology, but with different histories of human occupation and socio-economic development. The approaches of field visits and direct contact with local people encouraged the students to debate existing scenarios of land-use conflicts and to explore alternatives to improve rural development.

Initially, Training and Mobility of Researchers (EU-TMR) programmes were used to spread the results from the ECOMONT project to a number of university and non-university institutions. In the next few years, the course was organised within the framework of SOCRATES and ERASMUS European educational programmes and was open to students from different universities in Austria, Italy, Portugal, Spain, Hungary, Slovenia, and Slovakia. In the first years, the course focused only on recognising the main ecological values and processes of the contrasting territories found from the Ebro Basin to the Pyrenees. Afterwards, we added topics related to tools and methods for sustainable development of European mountain areas, and this was the course title several times. In the last few years, we have introduced the concept of key indicators of environmental change, mainly related to population loss in rural areas and to the change of traditional economies (Aguirre et al. 2000), with particular emphasis on historic utilisation (Fillat et al. 1999).

2.2 Main Objectives of the Course

There is a growing need to develop, teach, and apply successful problem-solving and interdisciplinary approaches on environmental sciences education. Some of most effective learning activities are fieldwork, although sites to be visited have to be carefully selected to reduce time and expenses as well as to take account of safety concerns. That is the case for the teaching sites selected to develop an interdisciplinary, international, and intensive course in NE Spain.

Throughout the course, the participants focus on exploring sustainable land-use alternatives to developing rural areas in the visited environments. The field visits are complemented with lectures given by scientists and experts, to express opinions face to face between policymakers and stakeholders and to promote discussions among the students on the different topics in their countries. The direct contact with the teacher staff at the visited sites proves especially useful in understanding human influences on landscapes, ecosystems, and species scales. Other learning activities of the students include workshops, presentations of group conclusions, assessments, and writing reports (Fig. 1).

The specific learning objectives pursuits with the course are:

- To analyse and distinguish contrasted landscapes from an ecological point of view
- To acquire understanding of the main driving forces at interdisciplinary scale
- To identify relationships between abiotic and biotic factors (for instance, soil and climate regime with vegetation)
- To analyse key indicators of the natural processes and of the historic land use
- To become familiar with the main parameters characterising climate, soil, vegetation, and diversity at different scales
- To identify socio-economic constraints and opportunities arising from abiotic factors in a territory (for instance, topography and road network, annual rainfall, and type of agriculture)
- To interact with local people, particularly with stakeholders, to obtain the information necessary to prepare a report
- To stimulate the capacities of expression, discussion, and critical awareness of the students

With this idea, we have been applying the recommendations of the "Convention of Bologna (19/06/1999)", that indicates: "We need to ensure that the European higher

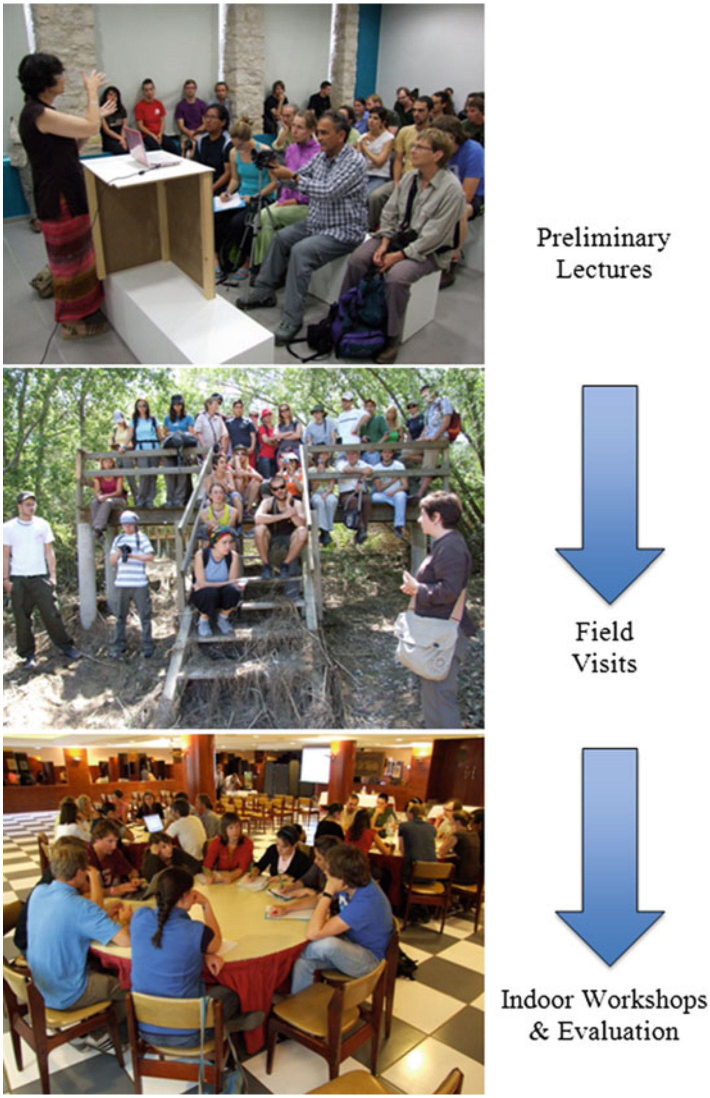

Fig. 1 Successive learning activities throughout the itinerant course

education system acquires a world-wide degree of attraction equal to our extraordinary cultural and scientific traditions… promoting inter-institutional co-operation, mobility schemes and integrating study, training and research programs".

Summarising, the overall objective is to complete and to reinforce the educational and professional development of graduates and master-level students in the fields of ecology, agronomy, geography, biology, forestry, landscape planning, or environmental technology.

3 Implementation and Timeline

3.1 Interest and Description of the Area

The itinerant course is developed along the NE Spain (Fig. 2), an ideal framework for environmental teaching because in a short distance we can find the widest ecological gradient of Europe with:

– Arid ecosystems: Central Ebro Basin
– Mediterranean mountain ecosystems: Iberian Range
– Alpine Mountain ecosystems: Pyrenees

The arid, Mediterranean, and Alpine environments encapsulated in this teaching area constitute a significant part of European and world ecological conditions. These environments include contrasting habitats in relation to geomorphology (Peña et al. 2002), climate (Cuadrat et al. 2008), vegetation (García and Gómez 2008), land use (Fillat et al. 1999), and soil characteristics (Badía et al. 2009). Moreover, the potentials and constraints of plains and mountain lands, regarding social and economic features (Instituto Aragonés de Estadística (2010)), can be found and discussed along the route of the course (Fig. 3).

In each environment, different sites are selected according to complementary ecological values and land-use potentialities and constraints, in a total of seven sites (Table 1).

3.2 Description of the Most Outstanding Features Taught and Discussed in Each Site

The teaching sites selected to be visited include natural areas with some degree of statutory protection and different land-use conflicts. The seven sites selected are the biggest river confluence on the Iberian Peninsula (Aiguabarreig), the salt-playa lakes in the Monegros Desert, the subarid steppes of Bardenas Reales, the shrublands in the Moncayo Natural Park, and the Alpine grasslands of the Spanish Pyrenees (Aragon, Hecho, and Ordesa valleys).

3.2.1 1st Teaching Site: Aiguabarreig

The confluence of the river Segre and the Cinca and with the Ebro River is commonly referred to as the Aiguabarreig, literally "mixing of the waters" (Badía 2009a; Badía et al. 2002).

Ecological Values: This is the widest river confluence in the peninsula and probably also the most interesting from a biological point of view, belonging to the Natura Network 2000. Because water reservoirs are built in the Ebro River (Riba-roja and

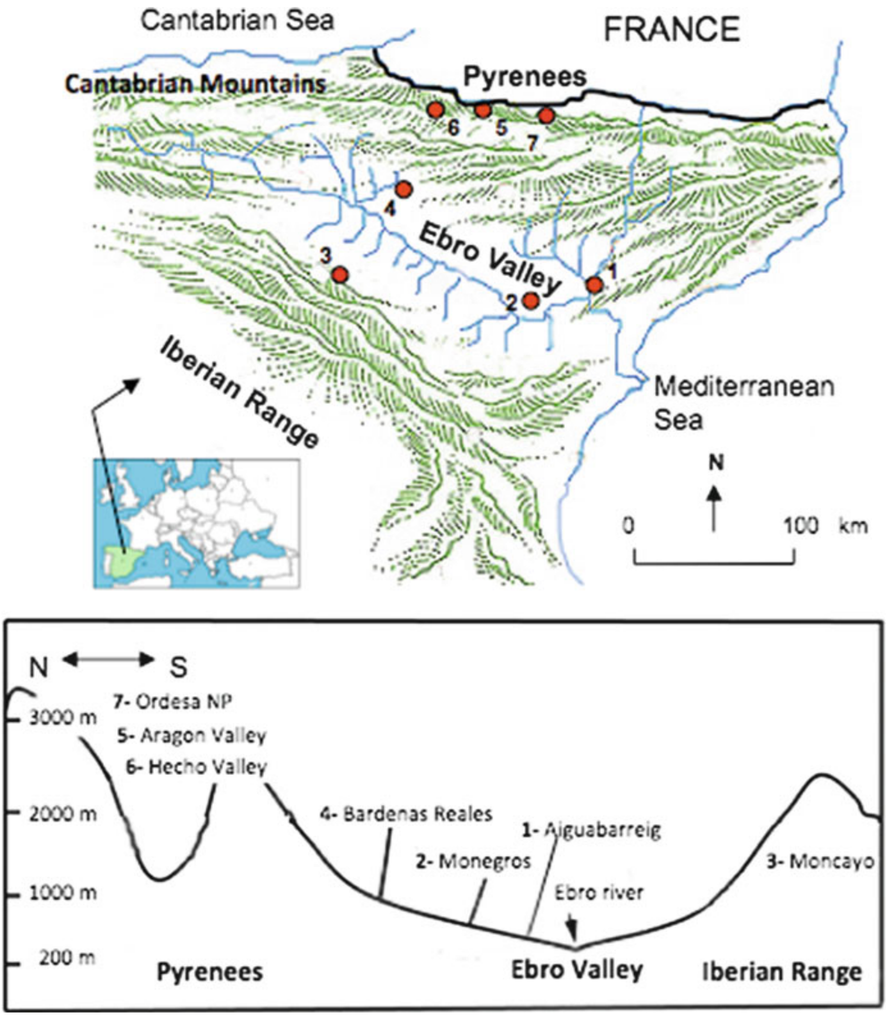

Fig. 2 Location and cross-section of the NE-Spain. The teaching sites are indicated by the *dots*

Mequinenza reservoirs), the area contains hundreds of metres of open water, with many small islands and riparian vegetation on the riverbanks. The Aiguabarreig is particularly significant as a mating, hibernating, and stopping-off point for migrating fauna, especially birds (Carceller and Xamani 2010). Wide fluvial terraces from the Quaternary (Badía et al. 2009) between vertical cliffs, showing Oligocene/Miocene materials, give a special geological and geomorphological interest to the area (Badía et al. 2008a).

Traditional and Current Economy: One of the longest histories of continuous and sustainable irrigation within Europe has occurred on the fluvial terraces of the Segre, the Cinca, and the Ebro rivers, with constant changes in crops, from olive trees or figs

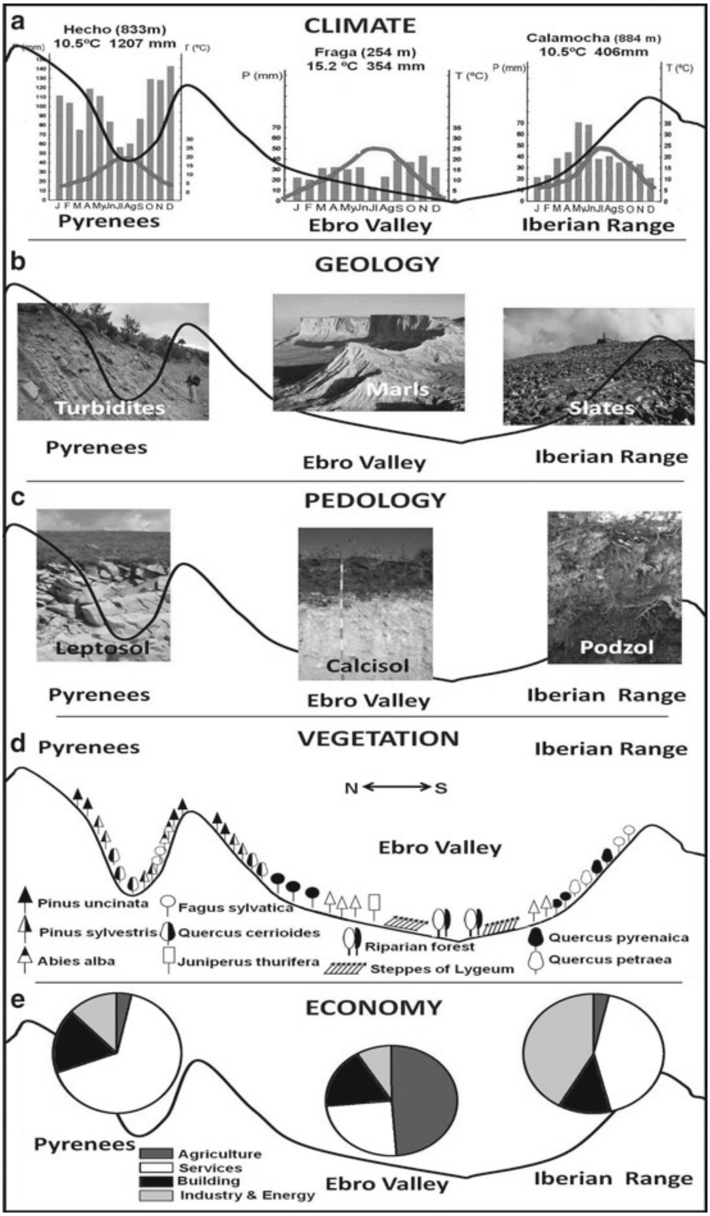

Fig. 3 Schematic cross-section of the three sectors of the Ebro Basin showing the contrasts of (**a**) Climate, (**b**) Geology, (**c**) Pedology (**d**) Vegetation, and (**e**) Economy

to orchards as well as wide fluctuations in density of population (nowadays about 16 inhabitants/km^2). The large handmade coal galleries have been transformed into industrial mining ones. Water reservoirs are used as hydropower stations, for irrigation and for tourism activities (canoeing, sport fishing, birdwatching).

Table 1 Topics and teaching sites relationships in each environment visited by the students

Visited environment	Selected teaching sites	Main land use	Discussed topics
Arid plain: Central Ebro Basin	Aiguabarreig: Natura 2000 Network	Coal mining and hydropower stations (dumps)	Global warming Pest invasions
		Intensive irrigated agriculture	Water and soil loss, quality losses, and pest invasions
	Monegros Desert: Natura 2000 Network	Rain-fed agriculture	Low economic inputs and rural depopulation
		Birdwatching at salt-playa lakes environment	Threats from land levelling, land consolidation, and saline water table
	Bardenas Reales: Reserve of the Biosphere (UNESCO)	Air Force training camp	Impacts on geo, flora, and fauna
		Seasonal grazing sheep	Soil erosion
Mediterranean mountain: Iberian Range	Moncayo: Natural Park	Grazing sheep	Grazing abandonment, shrub encroachment, and wildfire risk
		Wind farms	Impacts on birds and landscape
		Mediterranean crops	Agro-environmental subsidies
Alpine Mountain: Central Pyrenees	Aragon Valley: Natura 2000 Network	Alpine Ski Resort	Environmental impacts and high mountain urbanisation
	Hecho Valley: Natura 2000 Network	Agrotourism	Rural depopulation.
		Cross-country skiing	Forestry, land-use abandonment
	Ordesa Valley: European Geoparks Network and Reserve of the Biosphere	Ecotourism	Impacts of trampling and environmental eutrophication

Fig. 4 Teaching sites in arid environments: salt-playa lake in Monegros Desert (on the *left*) and eroded slopes showing polychromatic clays and sandstones strata in Bardenas Park (on the *right*)

Land-Use Conflicts: Dams in the 1960s in the Ebro River were built to produce hydropower, and recently, water has been also used to irrigate new lands and produce orchards with high-value fruits. The irrigation expansions into areas that have less favourable soil conditions produce unfavourable results and environmental problems (Badía et al. 2011a). Water reservoirs have increased numbers of fluvial birds and stimulated birdwatching and sport fishing, but different pests have been introduced, such as the zebra mussel, the Asian clam, the blackfly, and the European catfish.

3.2.2 2nd Teaching Site: Monegros Desert

The Monegros Desert, in the Central Ebro Basin, is considered the most arid inland region of Europe (Herrero and Snyder 1997).

Ecological Values: With regard to flora and fauna, the Monegros Desert is dominated by Mediterranean and steppic elements, with a remarkable number of endemics (Blasco 1996; Braun-Blanquet and Bolòs 1957; Pedrocchi 1998). From a geological point of view, what is remarkable is the presence of the Oligocene/Miocene evaporites (gypsum, anhydrite, carbonate, and halite) and detrital sediments (marls, limestones) in a general subhorizontal structure. With landforms as platforms, mesas, cuesta forms, glacis, V valleys, and U valleys (*vales*), the area is marked by numerous depressions, ephemeral saline lakes (Fig. 4), typical in areas where the evaporation rate is greater than the annual rainfall (Pueyo 1978).

Traditional and Current Economy: Rain-fed agriculture (barley-fallow rotation) combined with transhumant livestock (barley stubble as winter pasture) gives the highest gross added value to the agrarian sector (about 50 %). Nowadays, the Monegros Desert is being transformed into irrigate lands to harvest mainly alfalfa and corn.

Land-Use Conflicts: Sustainable agricultural land use in arid lands is one of the most important aspects considered in our lectures and decision workshops. Spain, like other arid countries in the world, needs to irrigate to guarantee its agricultural production. But there are strong side effects of irrigation on the environment (water table rises, water eutrophication, soil salinisation, and piping). The students participate in discussion workshops to propose alternatives to the rural development of the Central Ebro Valley arid lands. They have to take into account the geological and biological characteristics of the area and also the socio-economic factors, such as the declines in rural populations (currently 7.5 inhabitants/km^2) and ageing population (manpower shortages, wildfires, lack of services, infrastructure, etc.).

3.2.3 3rd Teaching Site: Bardenas Reales

Bardenas Reales is a 410 km^2 communal land that belonged to the Kings of Navarra up to the sixteenth century and that today – in terms of the "rights of use" but not the property – belongs to 17 surrounding villages, two Pyrenean valleys, and an abbey that have made up the "Community of Bardenas" for the last five centuries.

Ecological Values: It constitutes a desert-like landscape, with open habitats, bare soils, and Holocene erosion landforms, the consequence of climate and soil constraints (Fig. 3). Most of the territory is steppic, treeless, or with scattered groups of Aleppo's pine. Most habitats are uncommon in Europe and show interesting adaptations to environmental restrictions. Moreover, there are two special areas for birds with steppic species such as bustards and sandgrouse.

Traditional and Current Economy: The main use of Bardenas through time has been the seasonal grazing of sheep. Livestock reached maximum numbers in the Middle Ages, with around 300,000 sheep, reduced currently to a third of that. At the end of the fourteenth century, half of the territory was ploughed, but today, agriculture is a marginal activity. Since 1999, when the territory became a natural park, ecotourism has become a new economical resource.

Land-Use Conflicts: Grazing and agriculture must be adapted to the health regulations and the Common Agricultural Policy of the EU, which require significant efforts of managers to plan and to persuade stakeholders about the new requirements. Since the 1950s, there has been a 1,000 ha Air Force training camp. The Community of Bardenas receives a substantial income in exchange (more than 50 % of the total budget), but some opposition to this use is expressed by some NGOs.

3.2.4 4th Teaching Site: Moncayo Natural Park

This territory, with 450 km^2 and 15,000 inhabitants (32.5 inhabitants/km^2), surrounds the mountain of the same name, the central and highest point (2,320 m) of the Iberian Range, and a splendid representation of the Mediterranean mountains from an ecological and socio-economic point of view (Fig. 5).

Fig. 5 Mediterranean teaching site of Moncayo (2,373 m), the highest mountain in the Iberian Mountain Range covered by staggered vegetation along its slopes to glacier remains on the hilltop

Ecological Values: Moncayo, in most of its extent, is covered by evergreen oak forest (*Quercus rotundifolia*) and related Mediterranean vegetation. Furthermore, the only forests in Aragon of *Quercus robur*, *Q. petraea*, and *Betula pendula*, large formations of *Q. pyrenaica*, and isolated beech forest (*Fagus sylvatica*) complete the wooded island that Moncayo represents in the middle of a huge deforested territory. This territory also hosts important populations of birds and mammals and a remarkable cultural heritage. Since 1998, it has been a natural park.

Traditional and Current Economy: Human activities related to mining and forestry date back to the Roman times; in the Middle Ages, under Arab rule, the cultivation of cereal crops, almond, and olive trees complemented ancient livestock practices. Most of the territory was deforested to obtain timber and to expand grazing. In the 1950s, a policy of reforestation, mainly with *Pinus* trees, modified again the landscape. Nowadays, some industry, modern agriculture based on quality wine, olive oil production (guarantee origin labelled), and tourism make up the economy of the territory.

Land-Use Conflicts: The declaration of natural park in 1998 took several years to be accepted by the local population, fearful of land-use restrictions. However, the increase of tourism and the subsidies for farmers derived from agro-environmental measures of the EU have improved the economy and population. In the last decade, several wind farms have been built in municipalities that surround the protected area, providing important income. In recent decades, abandonment has caused loss of grassland by shrub encroachment and an increase of wildfire risk (Badía et al. 2011b).

3.2.5 5th Teaching Site: Aragon Valley

It is a site of 1,800 km^2 with a density of 9.5 inhabitants/km^2, situated in the Western Pyrenees, at between 800 and 2,600 m of elevation. It has been an important way since Roman times, and since the Middle Ages, the route to Santiago, European Cultural Itinerary, passes through this area.

Ecological Value: In spite of the impacts of road and railway networks and by ski resort installations (snow cannons and lifts with a capacity of 21,000 people/h), the territory maintains an acceptable landscape with a good representation of Pyrenean flora and fauna.

Traditional and Current Economy: The traditional way of life, as in the rest of the Pyrenees, was based on livestock, but tourism related to a valuable natural and artistic heritage and a mild summer climate became more and more important through the twentieth century. Furthermore, in the 1950s, one of the first ski resorts in Spain was built here – it currently covers a surface of about 4 km^2, with 40 km of Alpine ski slopes and 65 km for cross-country skiing, at between 1,600 and 2,400 m of elevation. In the last 30 years, heavy urbanisation developments have altered the valley, although this has provided high employment. Nowadays, the economic crisis threatens the sustainability of this model.

Land-Use Conflicts: The resort needs to improve its competitive capacity with other ski resorts in the Pyrenees that, with institutional economic support, are enlarging their installations more and more, threatening nature conservation. Attempts to attract visitors out of the ski season are an important challenge for the region.

3.2.6 6th Teaching Site: Hecho Valley

In the West Pyrenees, the Valley of Hecho comprises six villages with a total population of barely 700 inhabitants (3 inhabitants/km^2). Since 2006, this territory, along with its neighbouring Valley of Ansó, has been a natural park.

Ecological Values: The Valley of Hecho faithfully represents the humanised Pyrenean landscape, a result of centuries of a traditional land use mainly based on livestock (sheep and cattle) and forestry which has preserved most of the natural values, including many endemic plants, threatened raptors like the bearded vulture, and the last remaining populations of the Pyrenean brown bear.

Traditional and Current Economy: For centuries, the local economy has been based on agriculture, livestock, and timber production that have maintained local sawmills in the last few decades. Tourism related to mountaineering, hunting, mushroom picking, and other mountain activities has increased in the last few years. There are also some small agro-industries (cheese, biscuits, cold meats, etc.) and small trails for cross-country skiing. This site and the Valley of Aragon allow students to compare two kinds of tourism development in the Pyrenees: one intensive, related to a high seasonal occupancy in the ski resorts, and the other mainly based on ecotourism.

Land-Use Conflicts: The acceptance process of the new rules introduced by the natural park policy is ongoing. Some restrictions in forest exploitation for timber extraction and the difficulties in adapting local produce to the legal demands of the EU food production safety regulations are some of the challenges that local people have to face.

Fig. 6 Ordesa Valley (Pyrenees), a teaching site in an Alpine environment with a great contrast of landscapes, from outcrops in upper areas to deep forests on its mountainsides

3.2.7 7th Teaching Site: Ordesa Valley

This valley is located in the Central Pyrenees, surrounding Monte Perdido, the highest calcareous mountain in Europe (3,400 m). It was declared as national park in 1918, one of the oldest in Europe. The Ordesa Valley is also a biosphere reserve and belongs to the European Geoparks Network because of its scientific, rarity, aesthetic appeal, and educational values (Fig. 6). About 25 small villages surround it with 8,000 inhabitants (2.5 inhabitants/km^2).

Ecological Values: The five canyons that divide the area offer natural landscapes of forest, grasslands, cliffs, screes, glaciers, and other characteristic morphologies of medium and high Alpine Mountains as well as soils (Badía 2009b). Half of the Pyrenean flora and most of the birds, mammals, reptiles, amphibians, etc., occur in the protected area. Many ecological processes can be recognised and easily explained in the different canyons, including some uncommon ones such as the altitudinal zonation of forest or the inversion of vegetation belts. As a whole, the territory constitutes one of the most impressive European landscapes and the most ecologically valuable section of the Pyrenees.

Traditional and Current Economy: Agriculture, livestock, and timber extraction are used to constitute the traditional way of life in Ordesa, as in the valley of Hecho. Today, tourism (around 600,000 visitors per year) is the main economic source. Extensive grazing still continues in the territory, although the stock has been reduced to a quarter of its historical size. As a European Geopark, Ordesa Valley has an active role in the sustainable development of its territory through the enhancement of geo-tourism.

Land-Use Conflicts: The local population is largely in agreement about nature protection and about the framework of rules regarding the national park. Livestock distribution and soil disturbance by widespread populations of wild boar are producing some effects on grasslands and soils (Badía et al. 2008b; Bueno 2011). Trying to avoid tourism concentration in one place and time is a challenge for nature conservation, along with the improvement of local economies.

Table 2 Type of learning activities, places, and protagonists along the course

Teaching steps	Students	Place	Speakers
1. Preliminary lectures on the environmental and socio-economical framework of selected teaching sites	Whole group	Classroom	Professors, scientists, or researchers
2a. Study of cases "in situ" teaching sites	Whole group	Field visits and outdoor workshops	Local experts, managers, stakeholders
2b. Contributions of students: state of the art in each European country	Teams by country	Field	Students
3a. Indoor workshop on proposals for sustainable land use in rural areas	Teams by sector i.e. energy, agriculture, tourism	Classroom	Students and professors
3b. Indoor workshop: presentation of results	Teams by sector	Classroom	Students
4a. Evaluation of the students	By teams and individuals	Classroom	Professors
4b. Evaluation of the course	Individuals	Classroom	Students

3.3 Teaching Procedure

The learning activities of the students include preliminary lectures, field visits, workshops, presentations of group conclusions, as well as assessments and writing reports to be evaluated (Table 2).

3.3.1 Preliminary Lectures

To familiarise students with the teaching sites, they are provided with information in the form of lectures (Table 2) on the general characteristics of the area of study, including climate, soils, flora, fauna, history, and the network of the protected areas. Furthermore, different websites provide the students with additional information on some of the teaching sites (www.cienciadelsuelo.es, www.suelosdearagon.com, www.ipe.csic.es/floragon), with the advantages of multimedia programmes (Çaliskan 2011).

3.3.2 Field Visits

Field visits take 1 or 2 days at each site with walking and bus routes through representative habitats and landscapes. Field lectures are given by scientists (geologists, soil scientists, botanists, agronomists, economists, etc.), who are carrying out research projects in the area, as well as by local managers and stakeholders.

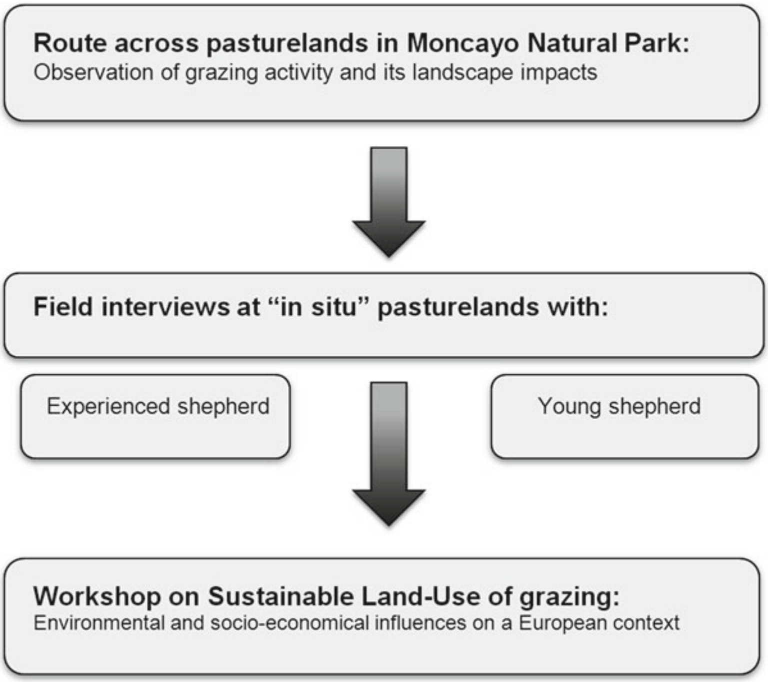

Fig. 7 Different steps to deal with traditional livestock management in the site of Moncayo

To encourage the capacity for analysing the environment at different scales (landscape, community, species) (Bayfield et al. 2000), emphasis is placed on the importance of selecting key indicators of change. For example, grazing levels are a key indicator of the relationships between grazing and shrub encroachment, the loss of heterogeneity in the landscape, and the rise of wildfire risk (Fig. 7).

In each teaching site, different ecological, social, and economic aspects, as well as their interactions, are introduced to the students, who are encouraged to discuss the issues raised. An example is when students of different nationalities are asked to outline the status of wind farms in their countries and their personal opinions about them. Another example is a debate on the advantages and disadvantages of different land uses in arid areas. The student's group participates actively in some activities to feel it close up (Fig. 8).

3.3.3 Indoor Workshops

An important element of the training is getting students to examine the various land-use scenarios they see, suggest alternatives, and develop indicators of change that could be used to monitor the sustainability both of current patterns of use and alternative scenarios.

Fig. 8 The students made some active outdoor workshops related to different sectors as tourism, industry, and farming

This is a theme of the field visits but is developed further by workshops in which the students undertake role-play and try and to develop alternative scenarios and examine the possible social, economic, and ecological implications.

The themes of the indoor workshops are based on the sites visited and utilise information acquired during field visits. Each workshop takes about a day of intensive discussion and subsequent presentation. Examples include the following:

I. *Developing Alternative Development Proposals for Arid Areas*.
In this workshop, the aim is to consider the problems of sustainable land use in arid environments and come up with alternative development proposals focused on three sectors: either energy, tourism, or farming (Fig. 9). Every one of each group has to prepare a set of proposals, outline their rationale and advantages, but also assess the possible impacts of their proposals and the key indicators of sustainability that they would use to monitor the effectiveness of their proposed scheme. In each case, the groups are asked to consider social, economic, and ecological impacts. The groups present their proposals at a notional village meeting, and members of other groups can take the role of villagers, farmers, or any other person who might come to such a meeting.

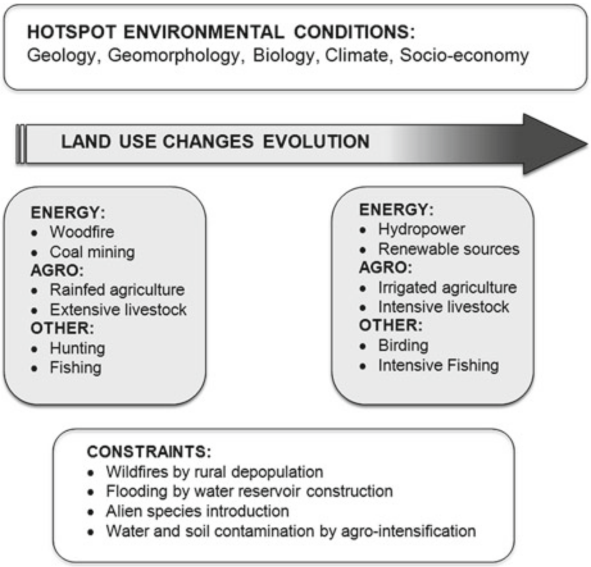

Fig. 9 Proposals for land-use change have to consider the environmental conditions of the site as well as their historical changes (example for Aiguabarreig site)

II. *Selecting Key Indicators of Change for Renewable Energy Development in a Mediterranean Area.*
Students are given an outline of the characteristics of a small mountain valley for which renewable energy proposals are to be prepared. Three groups consider a wind farm proposal, wood-based energy, or a hydro plant. The proposals are developed to examine the possible impacts of their scheme and have to show how the impacts would be mitigated and what key indicators of change would be suitable for monitoring actual impacts. The results of each group's deliberations are presented to the whole course and subjected to debate by all present.

III. *Choosing Between Three Development Scenarios for a Ski Area.*
In this workshop, students work together to choose key indicators of change for judging the sustainability of ski development plans. This is done using multi-criteria analysis and decision trees. The students split into three groups, taking the perspectives of developers, conservationists, or planners to decide how they would rank three contrasting development scenarios using the chosen indicators. Presentation of their conclusions takes the form of a mock public inquiry at which each group presents its conclusions. After each group's presentation, the other groups question and challenge the presenters on points of detail and opinion. These workshops are very popular with the students and stimulate their capacities of expression, discussion, and critical awareness. Furthermore, they provide a forum for detailed recall and debate of the issues, conflicts, solutions, and contrasting perspectives that they have encountered during the field visits (Fig. 10).

Fig. 10 Students hearing the presentation of a scenario for development of rural areas

Table 3 Schedule of the course showing the different learning activities

			Days														
	ACTIVITIES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	**Preliminary Lectures**		■	■	■												
2	**Field Visits to different environments**	Arid				■	■	■									
		Mediterranean								■	■						
		Alpine											■	■	■		
3	**Indoor Workshops**								■			■				■	
4	**Evaluation: Students&Course**																■

3.4 *Timeline*

The course length is 15 days with different learning activities (Table 3).

4 Evaluation

4.1 *Student's Evaluation*

Continuous evaluation of each student is carried out from the different learning activities. Their ability at teamwork is evaluated through their presentations in which each group proposes alternatives for development (ecological values, agrarian activities, energy sources, ecotourism) in the different locations (Alpine, Mediterranean, and Arid ecosystems). Every student gives at least one presentation at some point during the course. Their ability at individual work is evaluated through their written papers or reports on these subjects.

Table 4 Course evaluation by the students ($n=36$) of the school year 2010/2011

Question	Note
How satisfied were you with the duration of the course?	4.11
How satisfied were you with the dates of the course?	3.97
Judgement of academic/learning outcomes of the course	3.86
Judgement of personal outcomes of the course	3.67
How satisfied were you with the capabilities and expertise of the professors?	4.36
How satisfied were you with the overall quality of teaching of the course?	4.25
Do you think participation in the course will help you in your further studies/career?	3.94
Do you think participation in the IP will help you in finding a job?	3.09
Overall evaluation of the course	**4.27**

Scale 1–5: 1 = not at all (☹); 5 = very much (☺)

The evaluations carried out have the aim of verifying the acquisition or improvement in the competences:

- Capability to analyse the environment and to define the most important determining or limiting factors
- Understanding basic concepts in environmental sciences and specific techniques (for instance, basic measures of soil, key tree species regarding main type of climates, measures of biodiversity at different scales)
- Ability to select, to look for, to gather, and to interpret the most appropriate data to express opinions and make judgements about the topics of the course
- Refinement of the abilities necessary to undertake postgrad studies or to develop professional activities in the fields of environmental sciences, ecological restoration, and land management of protected areas

4.2 Course Evaluation

The opinions of the students have been collected by means of individual and anonymous questionnaires. Students are asked about how satisfied they were with the dates, duration, academic activities, capabilities and expertise of the teachers, pedagogical aspects, personal results, and the usefulness of the course for their future. The excellent evaluation up to now (Table 4) represents a strong endorsement of the members of the team involved and of the approach of the course. In 2010, the course was awarded the "Lifelong Learning Award" from the Austrian Federal Ministry for Science and Research.

5 Outcome of the Project

In the 13 years that the course has been running, nearly 400 students from ten European countries, as well as a few students from other countries (Taiwan, Iran) who were studying in European universities, have taken part in the course. Most of the students come from Faculties of ecology, environmental engineering, forestry science, environmental sciences, and agronomy, and some of them have been studying for a master's or a Ph.D. programme "Ecology and Biodiversity", a compulsory module in the main partnered universities.

6 Implications for Wider Practice and Conclusions

The selection of a study region with wide range of ecological diversity, and of conflicts between conservation and development, enables us to offer an itinerant course with exceptional educational benefits. The participation of researchers who carry out their work in the area (with the corresponding transferral of results), as well as of those responsible for the management, agricultural, and other uses of the area, enables the student to understand the study sites from multiple points of view. Students from different countries appreciate in the fieldwork the links between different disciplines and the functioning of the ecosystems and, moreover, have more time and opportunity to interact with professors.

The experience gained from this model of interdisciplinary and itinerant course, with its large teaching team and sites which are at the same time geographically close together and diverse, represents an example which can become part of the teaching programme for master's degrees in the field of natural sciences.

Overview

Background and Motivation

- The site is perfectly suited for environmental teaching since it represents the widest environmental gradient in Europe together with land-use conflicts in the context of nature conservation and development.

Innovations and Findings

- The teaching is based on scientific research results.
- The interdisciplinary training and experience of the teaching staff enable them to tackle a holistic analysis of the environment.

Implications for Wider Practice

- The experience gained from this model of interdisciplinary and itinerant course may be used in other teaching programmes in other fields of natural sciences.

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The Role of Concept Inventories in Course Assessment

Julie Libarkin, Sarah E. Jardeleza, and Teresa L. McElhinny

1 Introduction

Faculty of science in higher education are becoming increasingly aware of the importance of careful curriculum design for learning. The availability of online resources (e.g., The Science Education Resource Center; http://serc.carleton.edu/index.html), the presence of multiple journals for publication of higher education science curriculum (e.g., *Journal of College Science Teaching*; *Journal of Geography in Higher Education*), the emergence of opportunities to publish in highly ranked, multidisciplinary journals (e.g., SCIENCE Magazine's Education Forum), and the growth of discipline-based education research (DBER) in multiple science disciplines have all led to unique innovations in the university science classroom. The vast majority of these resources focus on the nature of curricular change, a smaller subset consider the role of goal setting in establishing effective instruction, and a similar minority attends to the importance of assessment in curricular design. In this chapter, we will consider the importance of assessment in curricular design, including

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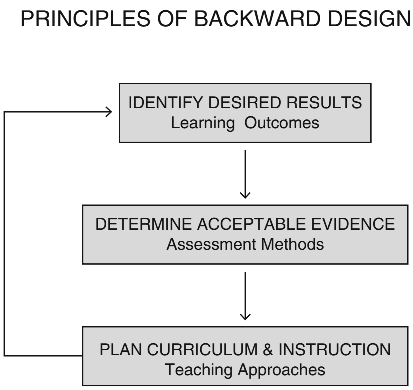

Fig. 1 The components of the Backward Design model (After Wiggins and McTighe 1998)

the importance of careful assessment design for geocognitive investigations of student understanding. We note that this chapter is written from a US perspective and uses terminology most common to the USA.

1.1 Backward Design

Backward Design is a curriculum design process that incorporates thoughtful consideration of instructional goals, conceptualization of assessment to evaluate achievement of goals, and instruction designed to meet goals (Wiggins and McTighe 1998; Fig. 1). Assessment data can inform the goal setting and curriculum planning processes, as well. Ideally, goals, assessments, and curriculum will be iteratively revised as assessment data provide insight into learning and instructional effectiveness.

The establishment of goals for instruction is not a simple process. Goals can emerge from multiple sources, whether from the faculty perspective of importance concepts and outcomes, from student articulation of desired learning, or from the larger community of experts engaged in instruction. The exact nature of goals is also not always clear. Are we interested in students *knowing*, *doing*, or *feeling*? What specifically should students know after a course, what should students be able to do, and how should students feel, believe, or value post-instruction? Generally, faculty focus on what students should know (Smith et al. 2009) after instruction. Although many faculty recognize the importance of skills performance and affective constructs as goals for instruction, the pathway to assessing goals is not always clear to faculty generally untrained in assessment practice.

The assessment component of the Backward Design triad is often overlooked or ignored yet is absolutely vital for gaining insight into whether or not a developed curriculum is effective. In addition, any revisions to instruction should be made in response to evidence; without appropriate assessment, we can never know if instruction was effective for meeting goals (Pellegrino et al. 2001). Assessment can be formative, occurring in the midst of instruction or a course, or summative, occurring after instruction has ended. Formative assessment of student performance offers both instructors and learners feedback, allowing top-down modification of instructor practice or bottom-up modification of learner practice. Summative assessment can provide faculty with research-quality data about the impact of an intervention on learner cognition.

The very nature of formative assessment allows for use of flexible instrumentation that can adjust to faculty and student needs; thus, assessment becomes part of classroom practice itself. The flexibility in design allows for assessment that is responsive to user needs; however, this benefit often results in a loss of validity and reliability for research purposes. Similarly, summative assessment, which is static in nature, loses the ability to respond in real-time to classroom needs while gaining research quality, providing attention is paid to validity and reliability. Summative assessment should be directly correlated to goals. As such, summative assessment can and should be designed prior to curriculum development, allowing for true testing of intervention effects (Wiggins and McTighe 1998). For example, concept inventories developed by individuals or small groups of faculty for use at a single institution are generally less valid and reliable than concept inventories developed by independent researchers without potential bias toward "proving" curricular effectiveness (Libarkin 2008).

Krajcik et al. (2008) offer an exceptional example of the consideration of goals, assessment, and instruction holistically in curriculum design, in what they call "learning-goals-driven design." This is an extension of the Backward Design model, incorporating best practice in instructional design to produce a goal setting, materials development, feedback, and revision cycle. This work indicates that careful consideration of learning goals – in this case devised from standards – allows production of assessments and curriculum that align with anticipated learning outcomes. The use of assessment data to revise curriculum is a central tenet of Backward Design and the extension proposed by Kracjik et al. (2008). For example, the impact of a lesson on middle school student conceptual understanding of chemical reactions yielded positive results, such that more students understood that the particular case of dissolution of powder in water would not create a new substance than before instruction. However, the authors noted that a high number of students still misunderstood this concept and revised their curriculum in response.

The third component of the Backward Design model, education itself in the form of curriculum development or instructional innovation, dominates the literature published on STEM (science, technology, engineering, and mathematics) education in both higher education and precollege settings. The wide array of curricular approaches published in the education literature, and the plethora of clearinghouses for curricular materials, illustrate the dominant roles curriculum development and instruction hold in the minds of faculty.

1.1.1 Backward Design in Higher Education Science

The consideration of goals and development of assessments *prior* to initiation of curricular development is a standard practice in precollege science education (Wiggins and McTighe 1998). In fact, the practice is so routine that new innovations have been published which expand on the model itself (e.g., Kracjik et al. 2008). The level to which faculty in higher education are aware of Backward Design, or even its components, is unclear.

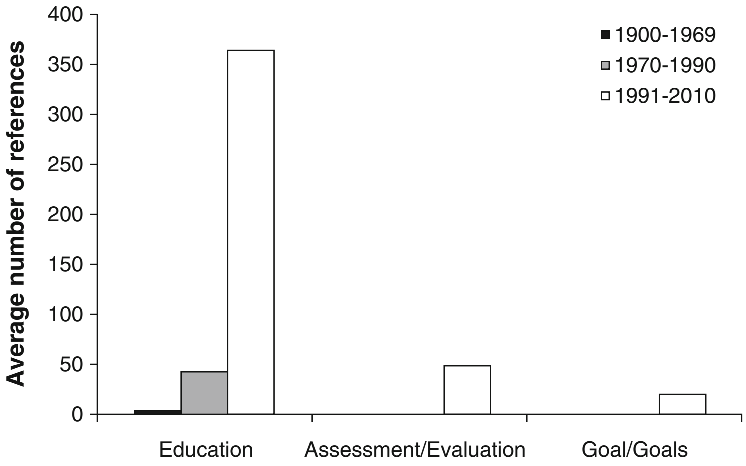

Fig. 2 Average number of education articles published in science journals over three time periods

While many faculty begin course development from the viewpoint of specific instruction, the "what" of the education process, only some are able to articulate goals ("why") of instruction or outline mechanisms for determining if instruction has achieved those goals. Backward Design has a recognized role in precollege STEM education. Similar use of Backward Design principles, although strongly advocated by leading scientific organizations (e.g., Pellegrino et al. 2001), has not occurred within the sciences themselves. A simple Google Scholar search for "Backward Design and education" yielded 306,000 references. In contrast, a search of 50,904 references on "education" housed within GEOREF, the premier geosciences reference database, yielded only eight results. This contrast suggests that the science education community, primarily focusing on precollege and informal education settings, is engaging in discourse that has not yet filtered to geoscientists working on education within the discipline.

A review of articles housed in the Web of Science reference database illustrates (a) the role curriculum and instruction have played in discourse about education in science over the past century and (b) the small yet growing value of assessment in education. The Web of Science houses materials published as early as 1889. A search of the Science Citation Index Expanded database within Web of Science was narrowed to include only materials focusing on the four core sciences of biology, geology, physics, and chemistry. This search approach was used to narrowly focus on papers emerging from within the disciplines, rather than from the science education community proper; this allowed for a focus on DBER in science. Subfields within science domains were included in the results. Only articles published in either journals or conference proceedings were counted.

Search results indicate that the focus on education within scientific publications remained constant until 1991 and has been growing steadily ever since (Figs. 2 and 3).

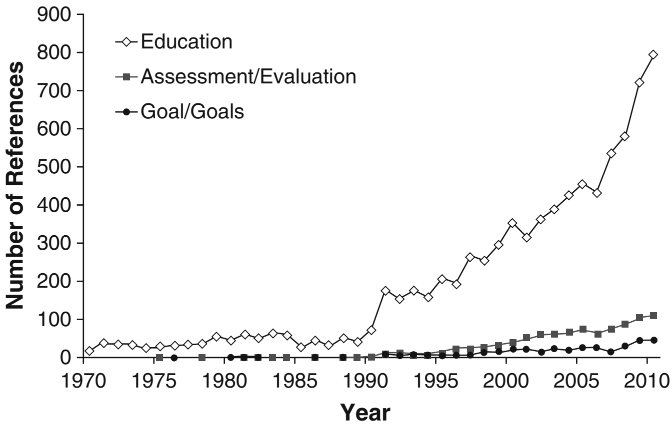

Fig. 3 Articles published from 1970 to 2010 returned with search term "Education" (*white diamonds*). *Gray squares* are Education articles with "assessment" or "evaluation" explicitly mentioned. *Black circles* are Education articles mentioning "Goal" or "Goals". These three categories align with the Backward Design triad of goals, assessment, and curriculum

Over the period 1900–2010, 8,359 articles were published in journals or conference proceedings under the topic "education." Of these articles, 992 and 410 also listed "assessment or evaluation" or "goal or goals" as a topic. While a thorough review of the material published in each article was not conducted, these results indicate that the vast majority of education-related papers do not explicitly discuss goals or assessment.

A closer look at the change in discourse about assessment in education indicates that both the overall number of education papers and the proportion of papers explicitly focusing on assessment have increased over time (Fig. 2). Prior to 1970, 210 articles related to science and education appeared in journals or conference proceedings, at an average of three articles per year. Before 1991, publication rates ranged from 19 to 73 per year, at an average of 43 articles per year. In 1991, the number of articles published in science and education leapt to 178 articles, with a 1991–2010 average of 362 articles per year. Articles with a goals or assessment focus did not appear until after 1969, at an average of 1 per year until 1991. After 1991, an average of 20 articles were published under the topic "goal or goals"; an average of 49 articles were published under "assessment or evaluation" over the same time period (Fig. 2).

The rise in publications related to goals or assessment in discipline-based science education warrants a closer look (Fig. 3). As noted above, education papers emerged from within sciences at a steady rate until about 1991. After this date, the number of publications increases at a rate of 29 papers per year. Over the same period, assessment-related papers emerging from science disciplines also increased, at a much lower rate of five papers per year. Finally, goal-related papers experienced a minimal increase of just under two papers per year.

Of the 8,359 papers related to education that emerged from the core sciences from 1900 to 2010, 12 % explicitly mention "assessment or evaluation" and 5 % mention "goal or goals." Similar analysis of publication rates within the geosciences alone yields comparable results. A search of the database GEOREF identified 10,654 publications related to education within the geosciences and related fields. Of these, 12 % discuss "assessment or evaluation," and 3 % discuss goals. While the preceding discussion of publication rates is limited in depth, this analysis suggests that the first two components of the Backward Design cycle, goal setting and assessment development, are given only limited attention by those scientists engaging in discourse about science education. In this chapter, we consider the need for effective assessment in higher education science, with particular focus on the geosciences.

1.2 The Assessment Triangle

The Cognition-Observation-Interpretation assessment triangle provides a valuable model for investigating learning (Pellegrino et al. 2001; Fig. 4). *Cognition* is the state of student knowledge, student skill development, or other cognitive constructs of interest. *Observation* allows us to consider student performance. For example, a multiple-choice test, open-ended questions, or literal observation of a student engaging in a task all provide evidence of student ability. *Interpretation* allows one to score observations and draw conclusions. An interpretation mechanism might be application of a statistical model to analyzing student data or a rubric for evaluating open-ended responses. The arrows represent the movement from cognitive model through data collection to analysis in a study.

Application of the assessment triangle to understanding learning in geoscience classrooms is an ideal means for ensuring that assessment of instruction is viable. The first step in the process is establishing what cognitive processes are being evaluated. In the geosciences, researchers have considered any number of possible outcomes resulting from engagement in geoscience instruction, including conceptual understanding (Libarkin et al. 2011 and references therein), spatial visualization (Black 2005), and affective characteristics such as attitudes or metacognition (McConnell and van Der Hoeven Kraft 2011). Articulation of a cognitive outcome is often coupled with explicit consideration of a model for cognitive change. For example, Hambrick et al. (2012) utilized the Circumvention of Limits model to explain observed differences between expert and novice mapping ability.

The nature of the observation used to capture information about student thinking depends upon the type of cognition being investigated. Very broadly, observations can be qualitative, quantitative, or semiquantitative; qualitative data can be thought of as anything that is nonnumerical, while quantitative data are scalar data. Semiquantitative data are those data for which ordinal numerical values, such as those used for scoring Likert scales, can be applied. For example, student thinking about climate change can be probed with an open-ended question,

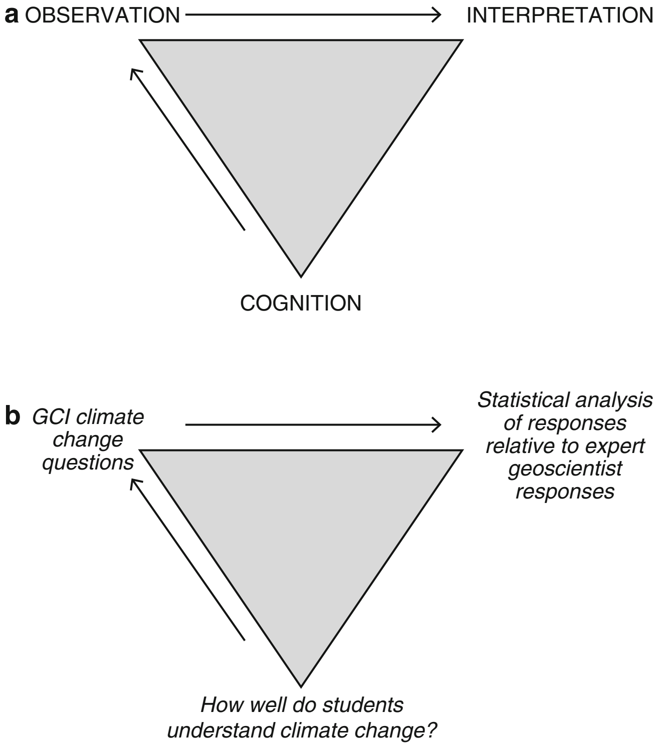

Fig. 4 The National Research Council's Assessment Triangle (After Pellegrino et al. 2001). (**a**) Components of the Assessment Triangle, with *arrows* to indicate normal conceptual flow when considering development of assessment. (**b**) An example application of the assessment triangle to conceptual understanding of climate change

with a Likert-scale question, or with a multiple-choice question (Fig. 5). In general, writing high-quality open-ended questions is easier than developing quantitative measures. For example, the multiple-choice question depicted in Fig. 5c is the result of survey and interview research into student alternative conceptions (conducted by someone other than the authors), careful writing of the correct and incorrect response options, submission to a central database (The Geoscience Concept Inventory Wiki: http://geoscienceconceptinventory.wikispaces.com/), revision by the GCI Team to align with best practices in question writing, and posting of the question for broader community review (Libarkin et al. 2011). At the most ideal, incorrect response options emerge from student responses to open-ended questions or interviews. This allows development of authentic response options that are effective measures of student conceptual state.

The type of data collected dictates the nature of the final corner of the assessment triangle, Interpretation. A complete discussion of quantitative or qualitative

a Open-ended question

What is climate change?

b Likert-scale question

Climate change is partially caused by human activity.

☐ Strongly Agree ☐ Agree ☐ Disagree ☐ Strongly Disagree

c Multiple-choice Question

What is a negative feedback loop in the climate system?

A. An initial change in the climate system leads to a response that has a beneficial effect on climate

B. An initial change in the climate system leads to a response that slows climate change

C. An initial change in the climate system leads to a response that speeds up climate change

D. An initial change in the climate system leads to a response that has a harmful effect on climate

Fig. 5 Types of questions that might be used to probe student thinking about climate change. (**a**) Open-ended question. (**b**) Likert-scale question. (**c**) Multiple-choice question (Theissen 2011) approaches is outside the scope of this chapter, although we recommend Patton (2002) for discussion of qualitative methods, DeVellis (2003) for discussion of quantitative approaches, and Trochim (2001) for a general discussion of research design.

Collection of qualitative data via a brief open-ended question (Fig. 5a) requires analysis that can reveal common themes in the data and provide an overarching sense of student responses. Analysis of responses to the question "What is climate change?" requires careful coding to reveal common themes emerging from the data. Analysis of Likert-scale and multiple-choice data is less time-consuming than thematic analysis of qualitative data, although generating high-quality quantitative questions is more difficult initially as described above. In addition, the effective use of statistical approaches can greatly enhance interpretation of semiquantitative and quantitative data.

The next sections focus on the assessment component of the assessment triangle. As shown, this component is often overlooked in discussion of educational effectiveness. Here, we focus our attention on conceptual learning, although other types of learning are equally important and can be considered. See McConnell and van Der Hoeven Kraft (2011) for discussion of affective learning in geosciences, for example.

1.3 Concept Inventories

The term "concept inventory" has grown in usage over the past two decades. Libarkin (2008) and Reed-Rhoads and Imbrie (2008) provide review of CIs published in sciences and engineering prior to 2008, and a number of new CIs have appeared since then. "Concept inventory" generally refers to a multiple-choice test developed by STEM scholars for use in higher education STEM courses. A few examples of qualitative concept inventories (e.g., Wittmann 1998) exist, and some concept inventories emerge from science education domains (e.g., Treagust 1986). The rapid growth in concept inventories has resulted in a community awash in tests, all of which are not created equal.

The most significant reason for differences in concept inventory (CI) construction and quality is the initial rationale for CI development. Some CIs are created to inform instruction, while others are created as research-quality tools. CIs created to diagnose student conceptions and inform instructional revisions tend to be of different structural quality (e.g., Hestenes and Wells 1992; Garvin-Doxas and Klymkowsky 2008; Smith et al. 2008) than CIs created as research measures (e.g., Treagust 1988; Bardar et al. 2006). The development process for instructional CIs generally follows a more streamlined pathway than CI development for research purposes. Instructional CIs are generally developed by faculty interested in understanding learning within their own classrooms, are driven by the needs of those courses, and typically have limited reference to the extensive literature on test development. In addition to these limitations in scope, instructional CIs are most often piloted within a few courses at a small number of institutions familiar to the developers.

By contrast, research CIs generally attend to best practices in test development and are either collaborations with psychometricians (scientists who study tests and test development) or rely heavily on the psychometrics literature. Research CIs rely heavily on the peer-review process, collecting expert feedback to ensure high quality, and alignment with goals. Research CIs are also responsive to student data, both quantitative responses and open-ended or think-aloud explanations of responses. Misalignment between student thinking and responses to multiple-choice questions should drive revision until questions are an adequate measure of thinking itself. While many CIs rely on classical test theory (i.e., simple statistics) for analysis of responses, state of the art in test analysis relies on item response theory models (e.g., Lord 1980; DeMars 2006) or other approaches (West et al. 2010). Movement beyond classical approaches allows for analysis of question performance relative to the abilities of students, provides opportunity to look for question bias toward subgroups within the sample (Libarkin and Anderson 2006), and allows for unique scoring, such as partial credit. Examples of multiple-choice CIs developed in alignment with best practice emerging from the scale development community are discussed in Treagust (1988), Bardar et al. (2006), and Libarkin et al. (2011, and references therein).

2 The Geoscience Concept Inventory

The Geoscience Concept Inventory (GCI) was begun in the early 2000s in order to provide a mechanism for broadly assessing learning in the geosciences (Libarkin and Anderson 2005). Initially, the GCI covered a limited range of concepts, initially reflecting the content expertise of the original developers (i.e., volcanology, tectonics), although a review of topics covered in textbooks was used to expand the GCI beyond the developers' narrow expertise. In 2005, the GCI consisted of 69 questions, with validity and reliability testing at over 40 institutions across the USA (Libarkin and Anderson 2005, 2007). This original instrument primarily focused on plate tectonics, geologic time, and Earth's history. In addition, Rasch analysis was used to link items. This allowed faculty and researchers to create subtests that aligned with course and research goals. Different subtests were comparable through Rasch-based scaling (Libarkin and Anderson 2006). The GCI has been used in a wide array of studies to measure effectiveness of geoscience instruction for entry-level students (e.g., Steer et al. 2005; McConnell et al. 2006; Russell et al. 2008; Teed and Slattery 2011). The GCI has also been shown to be a measure of general expertise (Hambrick et al. 2012).

Today, the GCI is a community-based instrument (Libarkin et al. 2011). The GCI has a dozen coauthors, with more submitting questions for consideration and inclusion. At this writing, the GCI contains 103 questions, with an additional 20 questions under review by the GCI Team that oversees alignment of questions with best practices in question writing. Once authors approve revised questions, questions are posted to the Geoscience Concept Inventory Wiki

Fig. 6 Screenshot of Geoscience Concept Inventory Wiki, from http://geoscienceconceptinventory.wikispaces.com. This wiki provides a space for the geoscience community to comment on questions, become coauthors through submission of questions for review and inclusion on the GCI, and link to a free site for pre- and post-course GCI assessment (http://www.lecturetools/ci)

Fig. 7 Screenshot of GCI coauthor page for the GCI wiki. http://geoscienceconceptinventory.wikispaces.com/Contributing+Authors. Authorship has risen to a dozen authors since launch of the wiki in 2011

(http://geoscienceconceptinventory.wikispaces.com; Fig. 6). Community members become coauthors through submission of questions or substantive revision of existing questions (Fig. 7).

An initiative to assist faculty in online testing of student conceptual understanding was undertaken in 2007 (Ward et al. 2010). Initially, this online site was built within a courseware system custom-built by an institution and was dependent upon grant dollars for sustainability. To ensure sustainability into the future,

Fig. 8 Screenshots from online site for concept inventory assessment, from http://www.lecture-tools.com/ci. (**a**) Registration page. (**b**) Test creation page

online testing is now available through collaboration with an academic start-up company, LectureTools. In a few steps, faculty can register a course, design a test that aligns with specific course goals, and upload a student roster (Fig. 8). Although initially created for the GCI, this site will expand to include concept inventory questions from a wide range of domains, including genetics (McElhinny et al. 2012).

2.1 Studies Using the GCI for Assessment

The rapid growth of CIs over the past two decades points to a need among scientists for reliable and valid measures of student learning. As in other domains, geoscientists engaged in education research and faculty interested in understanding student learning adopted the GCI for use in their classrooms and research. We have disseminated the GCI to over 200 faculty, although we do not know the extent to which the GCI has moved beyond these original users. The LectureTools/CI site described above was launched just 2 months ago, relative to this writing; 48 faculty have already registered with the site, and nine courses are actively engaged in testing.

We have identified a number of published studies that reference the GCI. Some of these were generated by the first author or her colleagues to describe the original GCI development (e.g., Libarkin and Anderson 2005, 2006, 2007) or expansion of the GCI into a community instrument with online testing functionalities (Ward et al. 2010; Libarkin and Geraghty Ward 2011; Libarkin et al. 2011). The remaining studies cover a range of topics, from narrowly focused studies of student understanding of a specific topic (e.g., geologic time, Teed and Slattery 2011) to studies of the efficacy of different instructional innovations (e.g., Steer et al. 2005; McConnell et al. 2006; Russell et al. 2008). The GCI has been implemented in studies of preservice teachers (e.g., Petcovic and Ruhf 2008) in addition to college students with nonscience majors and in field settings as well as within classrooms. Communication within our community also indicates that the GCI is being transformed for use with younger students (i.e., middle school) and has been translated into other languages (e.g., Spanish, Llerandi Roman 2007). Finally, the GCI is a useful tool for cognitive science efforts that require measurement of conceptual understanding (e.g., Kelemen and Rosset 2009; Hambrick et al. 2012).

3 Case Studies

As discussed, a number of researchers have used the GCI in investigation of learning in classroom settings. While classroom-based studies are the most common use for concept inventories, other uses are emerging as high-quality inventories become available. The GCI is a proxy for expertise, correlating quite strongly with performance measures of geoscience ability (Hambrick et al. 2012). The following two case studies illustrate the value of the GCI for programmatic assessment and the migration of principles for CI development learned to other domains.

3.1 Programmatic Assessment

The Michigan State University (MSU) Undergraduate Committee on Liberal Learning (UCLL) created a set of liberal learning outcomes that all MSU graduates should accomplish during their studies (Michigan State University 2011;

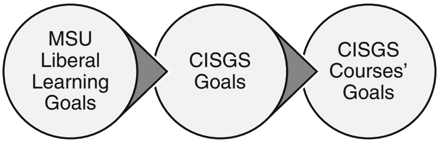

Fig. 9 Overlapping goals within the hierarchy of curriculum taught through the Center for Integrative Studies in General Science (CISGS) at Michigan State University

https://www.msu.edu/~freshsem/LLG%20%20GC%20combined%20table.pdf). The goals, generated over many years, have evolved into five specific constructs that students are expected to achieve upon graduation: analytical thinking, cultural understanding, effective citizenship, effective communication, and integrated reasoning. While all educational experiences are expected to help students achieve these liberal learning goals, some significant part of liberal learning occurs within the Centers for Integrative Studies. These centers are charged with providing students with general education in arts and humanities, social science, and general science.

Housed within the College of Natural Sciences, The Center for Integrative Studies in General Science (CISGS) is responsible for educating all nonscience majors in potentially the only science courses they experience at MSU. In addition to liberal learning, CISGS hosts its own set of goals (http://cisgs.msu.edu/about.html):

1. *Scientific knowledge*: Students will be able to describe some of the major concepts in science and be able to use them to explain important natural phenomena.
2. *Scientific development*: Students will be able to explain the contexts in which these concepts and results were developed and be aware of where these concepts may lead us in the future.
3. *Scientific practice*: Students will be able to discriminate between ideas that do and do not constitute proper subjects for science, give examples of how scientific understanding itself constantly evolves, and be able to use scientific approaches to solving problems in the natural world.
4. *Scientific appreciation*: Students will hopefully learn to value the efforts of physical and biological scientists as they continue to address practical needs and continue research into matters of fundamental and lasting importance.

Finally, individual courses taught within CISGS have their own, course-specific goals (Fig. 9).

In fall 2011, CISGS began a formal programmatic assessment that targeted two of the liberal learning goals, analytical thinking and integrated reasoning, and two of the CISGS goals, scientific knowledge and scientific appreciation. This programmatic assessment was undertaken to explore the impact and effectiveness of CISGS instruction.

The assessment plan utilized, wherever possible, published assessment instruments. In general, specific questions were modified to align with best practices in scale development. In all, this assessment measured student views and perceptions about science (scientific appreciation), science conceptions (scientific knowledge), sources used to inform decision-making (analytical thinking), and reasoning used in decision-making (integrated reasoning). In the context of this chapter, we will focus on science conceptions, including methods used and initial results.

The first step in the process of measuring conceptual understanding of students in the CISGS program was the identification of common conceptual goals across the wide range of courses taught within CISGS. Analysis of current and historical syllabi suggested three prevalent themes that ran across and within CISGS courses: Evolution, Energy, and Climate Change. Development of concept inventories to measure conceptual understanding of Evolution, Energy, and Climate Change for implementation in CISGS courses relied heavily on published concept inventories as well as ongoing development of questions by the authors. Questions were revised as needed to ensure that they aligned with best practice in scale development.

Students enrolled in CISGS courses were asked to complete a survey created by the CISGS Assessment Team. In some cases, faculty offered small incentives for completion, such as extra course credit; other faculty encouraged students to complete the survey; and still other faculty did not mention the survey to their students. Each participating student completed 14 concept inventory questions: six from a core theme and four each from the remaining two themes. The core theme identified for each student aligned with the specific course in which they were enrolled. Hence, those students enrolled in integrative bioscience courses ($n=1{,}033$) completed six Evolution questions, students in integrative physics courses ($n=252$) completed six Energy questions, and students in integrative geoscience courses completed six Climate Change questions ($n=351$). In all, roughly 36 % of students enrolled in CISGS courses ($n=1{,}636$) completed the survey in the first 3 weeks of classes, a relatively high completion rate for centralized data collection of this type. For the purposes of this discussion, we will focus on the questions (Appendix) used to measure Climate Change conceptions and the subset of students enrolled in integrative geoscience courses.

This "early semester" data collection provide invaluable information about student understanding of climate change prior to instruction (Fig. 10). Students have a weak to moderate understanding of climate change prior to instruction, with a mean score of about 2 out of 6. Consideration of response scores for individual questions provides some insight into areas that may be most conceptually difficult for students (Table 1). Over 70 % of students recognized that humans have had a role to play in increases in global temperatures over the past 50 years. Beyond this simple concept, however, students had significantly more difficulty. About 45 % of students were able to articulate the proper relationship between greenhouse effect and global warming, concepts that may not be clearly differentiated in student minds. Only about 25 % of students had a handle on more specific concepts related to the greenhouse effect, with 28 and 26 % of students responding correctly to questions about the role humans play in the greenhouse effect and the nature of greenhouse gases, respectively. Finally, about 10 % of students were able to answer more complex questions about climate change, with 11 % accurately explaining the concept of negative feedback loops and 13 % able to accurately predict the global impact of sea ice formation on Earth. These data provide insight into areas of

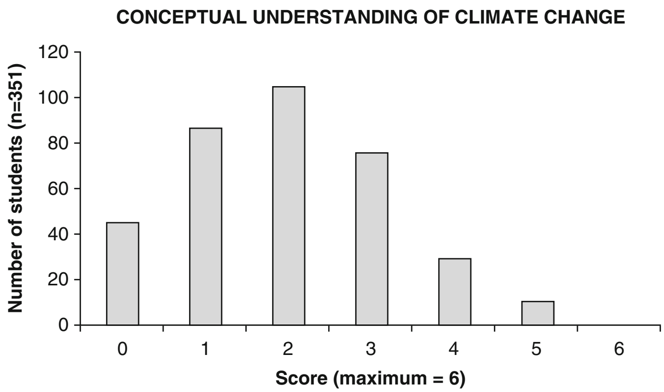

Fig. 10 Early semester results for six climate change concept inventory questions completed by US students enrolled in integrative geoscience courses for nonscience majors

Table 1 Average student scores for individual questions on the climate change concept inventory implemented during programmatic assessment

Question (see Appendix)	(%) correct
1. Which of the following statements about global warming over the past 50 years most closely reflects your viewpoint?	72
2. If human civilization had never developed on Earth, would there be a greenhouse effect?	28
3. What is a negative feedback loop in the climate system?	11
4. Which of the following best describes the relationship between the greenhouse effect and global warming?	45
5. What are greenhouse gases?	26
6. What would happen if a significant amount of new sea ice were to form in the Arctic Ocean?	13

conceptual weakness among students prior to instruction and areas for targeted instruction to encourage conceptual change. Results such as these are only meaningful when careful attention is paid to developing quality questions prior to collection of student data.

At this writing, instruction in CISGS courses participating in this programmatic assessment is still ongoing. Post-instruction administration of matched surveys will occur within the last 2 weeks of the academic semester. Comparison of differences between the early semester data and the post-instruction data will provide insight into the potential impacts of instruction on student learning. Discussion with faculty about these data, including consideration of the approaches used in instruction, will allow CISGS to identify instructional modalities that are most effective for enhancing student learning toward programmatic learning goals.

Finally, in addition to administration of existing CI questions, programmatic assessment offers an opportunity to collect student ideas about phenomena for which CI questions have not yet been developed. We discuss this, and the application of the Geoscience Concept Inventory development model to a novel domain, in the following section.

3.2 Applying the GCI Model to Other Domains

As in the geosciences, other domains need high-quality concept inventories that can be used to evaluate student conceptual states and engage in research to understand the impact of instruction on student learning. One such domain, genetics, hosts three concept inventories designed for university students: the Genetics Literacy Assessment Instrument (GLAI; Bowling et al. 2008), the Genetics Concept Assessment (GCA; Smith et al. 2008), and the Genetics Concept Inventory (GenCI; Elrod et al. 2008). A fourth instrument, the "two-tier diagnostic tool" (Tsui and Treagust 2010), was developed for use with high school students. These instruments predominantly fall within the category of instructional CIs, instruments created to inform learning within a specific course or set of courses. The GLAI is an exception; rather than being developed in response to an instructional need, the GLAI was conceived in response to goals for instruction established by a community (Hott et al. 2002).

The development of a research-quality concept inventory for use in genetics education research is both helped and hindered by the existence of these instructional CIs. On the one hand, genetics faculty are increasingly aware of the need to assess student learning as a normal part of instruction. This is transformative for science where, as shown earlier, many faculty simply do not explicitly consider the role of assessment in curriculum development. On the other hand, faculty are generally the users of CIs, not the developers; faculty also cannot be expected to be experts in best practice in instrument development. To many, instructional CIs look like research CIs and are used as such.

Providing the genetics community with a research CI for genetics is possible if best practices in research CI development are followed (McElhinny et al. 2012). This involves undertaking all of the steps utilized in development and expansion of the GCI, including involving the community in review and question development. As an important first step, existing genetics CI questions must be analyzed, with revision where necessary to ensure high alignment between student responses and actual conceptual understanding. McElhinny et al. (2012) provide a detailed discussion of the needs and process for engaging the genetics community in creating and reviewing a research CI for genetics. Here, we focus on the next steps in CI development, the writing of new questions to fill in gaps between existing questions and instructional goals.

During the CISGS programmatic assessment described above, students were asked to respond to several open-ended questions related to a range of topics. Two such questions "Where is DNA located in the human body?" and "Where are genes located in the human body?" provide valuable information about student ideas. Analysis of

Where in the human body is DNA found? CHOOSE ALL THAT APPLY
A. In cells
B. In mitochondria
C. In chromosomes

Fig. 11 Multiple-choice question developed from open-ended student response data

these data indicates that students have a wide range of ideas about this simple construct. For example, a fully correct response to the question regarding the location of DNA in the human body would state that DNA is within the chromosomes contained in the nuclei of most human cells (excepting anucleate cells such as mature red blood cells) and within the mitochondria. An expert might also note the presence of nonhuman DNA in symbionts and in food products in the gut. Student responses to this question contained many partially or nearly correct answers, such as "within every single cell of the human body," "chromosomes," and "cell nucleus."

These open-ended data can be used to develop multiple-choice questions of research quality. Synthesis of ideas from $n = 338$ students responding to one of the two open-ended questions allowed for identification of a small set of prevalent alternative (and nonscientific) conceptions. These, in turn, are used as attractive response options for use in a multiple-choice question (Fig. 11). Careful attention to standard rules for question writing allows initial production of a question that can be used for research. As with the climate change question discussed earlier (Fig. 5), this question must now undergo expert review and revision before it can be considered a question suitable for use in investigating student learning. Expert review can be facilitated through use of the web. For the GCI, for example, we use the Discussion option (see Fig. 6) within the wikispaces system to allow expert feedback on questions. Feedback is incorporated into question structure by the development team, with awarding of coauthorship to those experts providing feedback that substantially changes questions (Fig. 7).

4 Conclusions

Scientists who teach in higher education settings are generally very thoughtful about the nature of teaching and learning. Certainly, significant discourse about education exists, with myriad new curricula developed constantly. This emphasis on educational materials is reflective of the nature of faculty training; faculty are experts in their fields and have a strong sense of the important concepts within those fields. The body of knowledge about teaching and learning is, however, not necessarily familiar to college faculty. As a result, the influence of well-respected approaches to building effective instruction, such as Backward Design, may not be strongly felt within higher education classrooms.

Assessment is an important component of the curriculum design process. Faculty are well versed in the development of assessment useful for giving student's grades or providing students with feedback on their own progress. The development of assessment for research, for the investigation of instructional efficacy, is not as familiar.

The development and expansion of the Geoscience Concept Inventory (GCI) provides a useful model for the creation of concept inventories that can be used both for classroom assessment and research. The value of the GCI is in its attention to best practice in scale development and in its acknowledgement that a community must work together to build an effective, and broadly applicable, concept inventory. The importance of validity and reliability in instrument design cannot be understated; the very use of a concept inventory for research necessitates careful attention to asking questions about what exactly is being measured and how effectively.

The prevalence of concept inventories in many areas of science and engineering is evidence that faculty in higher education are interested in measuring learning outcomes within courses or programs. The existence of research quality concept inventories, developed for and by communities, can encourage the explicit inclusion of assessment into the next generation of materials being developed for use in higher education classrooms everywhere.

Overview

Background and Motivation

– Assessment is a key component of the curriculum design process.
– Scientists often ignore assessment as they engage in curriculum design or instructional innovations.
– Concept inventories, when developed in valid and reliable ways, can be an effective mechanism for measuring conceptual understanding, both before instruction and in response to instruction.
– Proper attention to design principles is necessary for any assessment, including concept inventories, to be valid and reliable measures of learning.

Innovations and Findings

– The Geoscience Concept Inventory (GCI) is a valid and reliable measure of student conceptual understanding.
– The GCI has evolved into a community instrument, authored and driven by the community of geoscientists.
– Scholars are utilizing the GCI to understand the impact of instruction on student learning, both for individual courses and for large programmatic studies.
– Lessons learned from the GCI in geosciences are easily transported to other disciplines.

(continued)

(continued)

Implications for Wider Practice

– The prevalence of concept inventories in many areas of science and engineering indicates that faculty need mechanisms for evaluating learning.
– Rather than relying on individual authors, communities of practice should collaborate to build research-quality concept inventories for evaluating learning.
– The presence of research-quality assessment instruments will provide needed mechanisms for assessment to become a more explicit part of the curriculum development process.

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Appendix

Climate Change questions used in programmatic assessment. Questions extracted from the Geoscience Concept Inventory: http://geoscienceconceptinventory.wikispaces.com/ATMOSPHERE#CLIMATE%20CHANGE

1. Which of the following statements about global warming over the past 50 years most closely reflects your viewpoint?

   (a) Global warming over the past 50 years is mostly caused by natural processes.
   (b) Global warming over the past 50 years is mostly caused by human activities.
   (c) Global warming has not really occurred over the past 50 years.
   (d) I do not know.

2. If human civilization had never developed on Earth, would there be a greenhouse effect?

   (a) No, the greenhouse effect is caused by humans burning fossil fuels.
   (b) No, the greenhouse effect is caused by humans depleting ozone.
   (c) No, there is no conclusive evidence that a greenhouse effect exists.
   (d) Yes, the greenhouse effect is caused by naturally occurring gases.

(e) Yes, the greenhouse effect is caused by plants giving off gases.
(f) I do not know.

3. What is a negative feedback loop in the climate system?

   (a) An initial change in the climate system leads to a response that has a beneficial effect on climate.
   (b) An initial change in the climate system leads to a response that slows climate change.
   (c) An initial change in the climate system leads to a response that speeds up climate change.
   (d) An initial change in the climate system leads to a response that has a harmful effect on climate.
   (e) I do not know.

4. Which of the following best describes the relationship between the greenhouse effect and global warming?

   (a) The greenhouse effect and global warming are likely the same thing.
   (b) The greenhouse effect and global warming are likely unrelated.
   (c) Without the greenhouse effect, there would be almost no global warming.
   (d) Without global warming, there would be almost no greenhouse effect.
   (e) There is no definite proof that either the greenhouse effect or global warming exists.
   (f) I do not know.

5. What are greenhouse gases?

   (a) Gases in the atmosphere that absorb infrared energy.
   (b) Gases in the atmosphere that absorb ultraviolet energy.
   (c) Gases in the atmosphere that cause rain to become acidic.
   (d) Gases in the atmosphere that are produced as plants grow.
   (e) I do not know.

6. What would happen if a significant amount of new sea ice were to form in the Arctic Ocean?

   (a) An increase in the amount of ice in the ocean would lead to more coastal flooding.
   (b) A decrease in the occurrence of extreme weather events would lead to fewer hurricanes.
   (c) A decrease in the temperature of the ocean would lead to a cooling of the planet.
   (d) An increase in the reflection of solar energy would lead to a warming of the planet.
   (e) A decrease in the absorption of solar energy would lead to a cooling of the planet.
   (f) I do not know.

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