The Math You Need, When You Need It: Modular Student Resources to Encourage Successful Incorporation of Quantitative Concepts in Introductory Geoscience

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PROJECT SUMMARY

Intellectual merit: This project addresses the urgent need for inclusion of quantitative skills in introductory geoscience. Quantitative literacy (QL) is a major goal for most general education science courses and mathematics education research suggests that students learn best when mathematics is given in context, represented in a variety of ways and revisited multiple times. Introductory geoscience provides a unique opportunity to utilize these "best practices" to increase the QL of all students. However, students' diverse mathematical backgrounds and preconceived notions about math present significant barriers to effective instruction in QL through geoscience. In addition, we present evidence that quantitative skills included in science courses do not, alone, increase the QL of students. Instead, recent studies (Baer) suggest that students learn more effectively and remain enrolled if there is external support for them to learn and develop quantitative skills as they are applied in class.

To address these difficulties and important issues, we propose a project designed to advance knowledge and understanding across geology and mathematics through innovative instructional techniques. We will create a web-based student-centered program – the math you need when you need it – that can be customized to, and run concurrently with, any introductory geoscience course. This unique program includes: 1) pre-assessment of students' quantitative skills, 2) modular, self-paced, student-centered instruction for under-prepared students and 3) post-assessment to evaluate the effectiveness of the program. When combined with classroom examples of quantitative concepts in a geoscience context, this project addresses many concerns about the nation's STEM education (NSF 2006; NRC, 2003; 2005), including difficulties with teaching large numbers of students from diverse backgrounds, course adaptation to students' preexisting knowledge, and student self-assessment and monitoring

The PIs are uniquely qualified to execute this project. Since 2000, Baer has led Highline's program that forms the foundation for this project, MathPatch. Wenner has worked with colleagues in the geology and mathematics departments at Oshkosh to develop a course (offered since 2004) that uses mathematics to address geologic problems. Baer and Wenner are also co-editors of SERC's Teaching Quantitative Literacy website, a resource for faculty who wish to apply advances and developments in the pedagogy of QL to their own teaching of introductory geology. Burn is a mathematics instructor at Highline and provides much-needed expertise in mathematical instruction assessment and project evaluation.

Broader impacts: This project has broad implications for increasing QL in the undergraduate population and in the greater US population. The mathematics community has identified QL as an important goal for higher education as graduates become integrated into our increasingly number-oriented society. The modular nature and the tailoring of instruction to meet individual student needs support increased QL in students with diverse backgrounds and mathematical abilities. The project is also designed to impact geoscience faculty who wish to embrace inclusion of quantitative aspects of geoscience in their courses with little extra effort and minimal alienation of under-prepared students. In addition, the proposed project has the potential to be replicated across both academic disciplines and institutions wherever the application of quantitative skills is a barrier to student success (NRC, 2002).

Use of the increasingly popular SERC web server will ensure nearly instantaneous widespread dissemination and ready application at a variety of institutions. Past experience with SERC suggests that their web pages are widely read, respected, and utilized by geosciences educators around the United States. Dissemination will also occur in a more traditional fashion – education journal articles and presentations at regional and national meetings.

INTRODUCTION

Quantitative literacy is increasingly important in our number-filled society (Steen, 2001); college level science classes represent an important step in the numerical education of our citizenry. Although largely untapped for the important quantitative skills they engender, geoscience classes could exemplify a connection between real world observations and the quantitative models derived from those observations. However, the difficulties in teaching quantitative skills to introductory geoscience students are numerous and diverse and include pervasive math anxiety and a range of skills in incoming students and lack of preparedness on the part of both instructor and student. Overcoming these difficulties is critical if we are to succeed in transforming introductory geoscience education.

Geoscience educators and researchers recognize multiple reasons for greater quantitative content in introductory geoscience courses (e.g., Geo-Study Mathematics Panel, 1965; NSF, 1998; Powell and Leveson, 2004; Macdonald et al., 2000 and references therein). First, because geoscience is fundamentally a quantitative science, any geoscience course that is taught with little or no quantitative content significantly misrepresents the science. Second, as the first course most future geoscientists take, introductory geoscience should provide opportunities for students to begin to deal with geologic problems quantitatively, thus preparing them for future geoscience courses and careers. Third, introductory geoscience is an important vehicle for communicating effective methods of integrating math and science to the large number of future K-12 teachers who enroll (National Science Foundation, 1998). Finally, mathematics is a basic tool used in scientific problem solving and a requirement for scientific literacy; we cannot truly teach science without math (AAAS, 1995; deCaprariis, 1997). Colleges across the country have used the above reasons as incentive to increase the quantitative content not only in geoscience classes but also across the entire collegiate curriculum (Ireton et al, 1996; NRC, 1996, Rotham and Narum, 1999)

Whereas the above reasons for increasing quantitative skills in science courses are significant, hindrances at both faculty and student levels are equally numerous. For faculty, they include a lack of preparation for teaching quantitative skills, the lack of quantitative classroom materials provided by most publishers, and a perception that including quantitative skills in a course will lead to lower faculty evaluations and/or enrollments. Student obstacles include anxiety about learning mathematics, diversity in mathematical preparation, and the wide variety of mathematical skills needed for introductory geoscience courses. Many publishers design textbooks to reduce learning obstacles and have turned to treating the geosciences in a largely qualitative way (Shea, 1990). Because textbooks have shied away from presenting the quantitative aspects of geoscience, the problem of finding classroom time to help unprepared students is created. Many faculty members feel that one may have to teach fewer geoscience topics to accommodate quantitative geoscience instruction (Shosa et al., 2000).

Providing external resources that give students experience in quantitative skills needed for introductory geoscience classes without taking away from valuable class time may be one solution to the significant difficulties experienced by both students and faculty (Kenyon, 2000; Linneman and Meyers, 2000). These resources need to adapt to a variety of situations, show clear applications in a particular geoscience course and cater to individual students' needs in order to be successful. In addition, they should draw on research from the mathematics education community suggesting that application, repetition and transfer must be integral parts of any mathematics teaching resource.

We propose a series of web-based self-paced modules - "the math you need, when you need it" - that focus on quantitative skills that students need in introductory geoscience courses. In addition to quantitative concepts, the modules will be inextricably linked to multiple geoscience subjects for which the skills are essential. Web-based modules are the ideal platform for these student resources because they are accessible at any time of the day or night, easy to disseminate, can be used at the student's pace and provide a relatively comfortable platform (the Web) for student learning (Myers, et al., 2002). Instructors can assign individual modules that students need to master quantitative skills in introductory geoscience courses that emphasize them. These self-study modules will allow students to develop specific mathematical abilities immediately prior to using them in the geoscience classroom. These much-needed resources will provide students with opportunities to become mathematically sufficient without robbing faculty of valuable class time or important geologic context.

BACKGROUND

The proposed project is an outgrowth of several successful projects conducted by Baer and Wenner. MathPatch, a successful project at Highline Community College (Baer), offers students support for quantitative skills and improved student retention and performance (Baer et al. 2002, 2005). At Oshkosh (Wenner), three faculty members (two geoscience and one mathematics) received funding to develop and run a problem-based inquiry seminar to combine mathematics and geoscience. This seminar has been successfully run for two semesters. Wenner also designed and piloted a project aimed at improving the teaching of quantitative skills and increasing quantitative content in introductory geoscience classrooms – the Teaching Quantitative Literacy website housed at SERC. Baer has contributed nearly half of the content on that website and the dual quantitative-geoscience resource has been well received in the larger geologic community. The proposed project will build on all of these important advances in the quantitative education of geoscience students.

The MathPatch experience at Highline Community College

Highline Community College provides a good case-study of the barriers to teaching geosciences quantitatively. At Highline, 85% of students enter with mathematical abilities below college level (intermediate algebra) (B. Maplestone, pers. comm., 2006). Moreover, even the students who are in or have passed college-level mathematics courses have difficulty applying low level mathematical skills to problems in geosciences [a problem common in other academic disciplines such as chemistry and physics (*e.g.,* Cerreto et al, 1977; David, 1990)]. A significant number express that their primary concern for being successful in the introductory geoscience courses is the mathematics required.

In 2000, frustrated by students' inability to complete even simple quantitative tasks, the geoscience faculty at Highline Community College sought assistance from their mathematics colleagues. The outcome of these discussions was the development of a new course (supported by a Title 3 grant) to be taken concurrently with introductory physical geology. The resulting one-credit course, nicknamed "MathPatch" is composed of 10 modules, co-written by mathematics and geoscience faculty, and taught in the first 5 weeks of a 10-week quarter. Unlike some shadow courses described in the literature (*e.g.,* Lutz and Srogi, 2000) in which geology applications supplement a core math course (such as calculus), Highline's course focuses on applying mathematical techniques to the geosciences in a concurrent course.

Significant results when MathPatch is offered.

At Highline Community College, we have found that supporting students' mathematical skills in the geoscience classroom significantly decreases student withdrawals and failures, in some cases by as much as one-third (Baer et al., 2002). When we first offered MathPatch, students were not required to take the course and attrition rates for that period were high. For those students who chose not to receive the additional instruction provided in MathPatch, 60% <u>did not</u> complete the Physical Geology course successfully. In contrast, 93% of the students who chose to take the MathPatch course completed the concurrent geoscience course successfully and received credit for both classes.

Based on these results, we began to require MathPatch as a co-requisite for Physical Geology; students were not permitted to opt-out, and attrition rates dropped. Prior to the use of MathPatch, 27% of students dropped the course; in the years that MathPatch was mandatory, attrition in Physical Geology classrooms dropped to 16%. The lower attrition rate with increased quantitative skills was unexpected since we assumed that negative student attitudes toward mathematics would increase attrition in courses with significant quantitative components. However, results from inclusion of MathPatch at the introductory level suggest that the quantitative skills themselves may not be the reason that students feel inadequate. Instead, giving the students the tools they need to succeed, and making explicit connections between qualitative and quantitative aspects of geoscience may go far in helping students to overcome their fear of science and math. In addition, institutional and departmental support for both students and faculty to explore the meaningful use of quantitative skills contributes significantly to the successful incorporation of mathematics in introductory geoscience courses.

Increased student success is another benefit to supporting students' mathematical abilities. Results of the MathPatch study suggest that students in MathPatch perform better in all parts of their geoscience courses (tests, quizzes, labs, homework) than students who did not enroll (Baer et al., 2002). Average student performance in an individual instructor's sections with MathPatch improved from 73% to 81% (Baer et al., 2002). As a result of the positive correlation between the MathPatch course and increased performance, Highline Community College continues to require MathPatch as a co-requisite to its Physical Geology course; however, the program is now designed to exempt students who demonstrate mastery of quantitative concepts on a placement exam.

Increased quantitative content in geoscience courses

Because Highline's geology program requires students to be competent in quantitative concepts, the quantitative content of geology courses has increased significantly since the inception of MathPatch. Although there are many obstacles to requiring significant quantitative skills from introductory students, Highline Community College provides support for faculty who show students that geology is a quantitative science. Because students take a co-requisite mathematics course, geoscience faculty at Highline know that quantitative skills are expected to be an important component of their introductory courses. As a result of departmental support and expectation, the physical geology course at Highline Community College has changed over the past seven years from being a dominantly qualitative course to having quantitative skills infused throughout the curriculum. At the same time, because of the support given by the MathPatch class, attrition in Physical Geology has dropped significantly (Baer et al., 2002).

The results of MathPatch suggest that students respond positively to support for quantitative skills. However, supplemental materials must be made mandatory for under-prepared students – they will not choose to seek assistance on their own. Students are poor at determining their own level of quantitative mastery; tests or other evaluative materials are required in order to accurately determine previous or learned skills. These evaluative materials are also used to exempt students who do not need the supplemental instruction from the co-requisite. Feedback from those who viewed presentations (Baer et. al 2002, 2004, 2005) at professional meetings suggests a desire for web-based modular supplemental support with a variety of skills applied to different types of modules. Participants suggested web-based modules so that they would be available in an easy manner outside of class time. We anticipate that by making similar ”the math you need, when you need it” support available to introductory geology students (and faculty) at a variety of institutions, we will see increases in quantitative content <u>and</u> student success similar to those found at Highline with the implementation of MathPatch.

Other instances of "the math you need, when you need it" approaches

In addition to the MathPatch experience, considerable support for the idea of using modular, student-centered materials to support student success exists in the literature (*e.g.,* Reed, 2001; Russell, 1974; Elaine, 2002). Our project – "the math you need, when you need it" – has many similarities to the concept of just in time teaching as used in computer training (*e.g.,* Comer, 1996). This type of teaching has been shown to be effective at supplying information and resources needed to complete tasks (*e.g.,* Weintraub and Martineau, 2002). It is a variation on student-centered instruction (SCI) where students are made responsible for their own learning and hence are more motivated, have greater retention, and more positive attitudes toward learning (Felder and Brent, 1996; Bonwell and Eisen 1991; Johnson, et al., 1991; McKeachie, 1986; Meyers and Jones, 1993). It does differ significantly from the just-in-time technique used by Linneman and Plake (2006).

Intuitively, "the math you need, when you need it" has many advantages. Because students learn a technique immediately prior to using it, retention should be improved (Okeeffe, 2006; Hofmann and Hunter, 2003; Weintraub and Martineau, 2002). Results from studies in fields other than geology suggest that when relevance is made clear in a timely fashion, students are more motivated to learn than when mathematical techniques are taught but not applied until some time in the future (Mandell, 2006; Hoyt, 1996).

GOOD IDEAS FROM THE MATHEMATICS EDUCATION COMMUNITY

Since 2004, Wenner and Baer have been working on a number of web resources for introductory geoscience instructors; these resources discuss the importance of quantitative literacy and are housed at the Science Education Resource Center (SERC) at Carleton College. The quantitative literacy website is designed to help faculty members to readily increase the quantitative skills that are used in their introductory courses by providing information and teaching tips. The web pages are written in the context of "good ideas" for teaching quantitative skills from both the geoscience and mathematics education communities (workshops by PKAL 1999, and NAGT 2000, 2002, and 2004):

- place mathematical concepts in context
- use multiple representations
- use technology appropriately, and

- do in depth-problems that last more than one day and revisit quantitative skills frequently.

These "good ideas" will provide a foundation for the mathematical modules designed for this project.

1. Place mathematical concepts in context

Scientific and mathematical inquiry involves the use of appropriate quantitative skills in the context of a question or problem. However, many undergraduate mathematics courses are geared toward theoretical concepts and manipulation of equations. The mathematics education community (e.g., Silver, 1985; Adams and Hamm, 1998) is concerned with making students mathematically powerful – capable of making connections, raising questions, utilizing numerous mathematical techniques and testing and verifying mathematical models (e.g., Silver, 1985; Adams and Hamm, 1998). Making mathematics powerful means that it has a sense of purpose and, thus, seems more significant to the student (Adams and Hamm, 1998). Emphasizing understanding and student interest makes learning more meaningful and fun and often pushes students to seek new ideas on their own (Skemp, 1978; Adams and Hamm, 1998).

Doing mathematics with a "sense of purpose" or putting mathematics in context speaks to the problem of transfer from mathematics classes to other courses. Many geoscience instructors observe that students have less difficulty with math when it is given a real world context or when students care about the question or problem they are addressing (NAGT workshop, 2002). Explicitly connecting mathematical skills to the geologic framework will help students to understand that mathematics is a powerful tool for understanding the physical world. Our modules will help students to make connections between the mathematics they need for geology and applications of that math within their geology course. The modules will provide real-world problems to solve using mathematics that will then be revisited in class.

2. Use multiple representations

Research in mathematics education suggests that students in mathematics classes benefit greatly from multiple representations of a mathematical concept and the connections among those multiple representations (*e.g.,* Dufour-Janvier *et al.*, 1987; Kaput, 1992; Jiang and McClintock, 2000; National Council of Teachers of Mathematics [NCTM], 2000; Schultz and Waters, 2000; Friedlander and Tabach, 2001). Representations may include verbal, numeric, graphic, and algebraic/symbolic (*e.g.,*AMATYC, 1995; Friedlander and Tabach, 2001). The representation of mathematical concepts in a variety of forms throughout all science and mathematics curricula addresses the importance of recognizing diverse student learning styles (*e.g.,* Gardner, 1983; Fleming and Mills, 1992; Bykerk-Kauffman, 1995). Because many students may learn differently than their instructors, students are often most comfortable with multiple approaches. Students can increase problem solving ability when they are given the opportunity to make choices about representations that are appropriate for a given situation (Schultz and Waters, 2000). Providing students with occasions to explore approaches that work for them may help them to make explicit connections between differing approaches, and come to a more meaningful mathematical understanding (Pape and Tchoshanov, 2001).

Like the idea of putting mathematics in context, the use of multiple representations may also help students with transfer and connections between mathematics courses and other courses in which they encounter mathematics. Modules developed for this project will include the use and connection of multiple representations in the form of verbal, graphical, numerical, symbolic and tabular data. Emphasis will be placed on deeper understanding of mathematics by making explicit connections among multiple representations (Pape and Tchoshanov, 2001; Schultz and Waters, 2000; Greeno and Hall, 1997). When appropriate, students may choose the representation that is most easy for them to learn from.

3. Use technology appropriately

Mathematics educators are at the forefront of teaching quantitative skills using appropriate technologies. The NCTM (2000) identified technology as one of the six principles for school mathematics, stating: "Technology is essential in teaching and learning mathematics; it influences the mathematics that is taught and enhances student learning."

The mathematics community has explored many ways that technology can enhance learning (*e.g.,* Jacobson and Kozma, 1999). One of the most successful is through the connection of multiple representations (*e.g.,* Jiang and McCormick, 2000; Ozgun-Koca, 2001; Alagic, 2003). Computers and graphing calculators depict and connect multiple representations (particularly the connection of visual, numeric and symbolic representation). Students can also work to model their own observations about some physical phenomenon using readily available software like Excel or Flash. This empowers students to perform mathematics that they may not otherwise have been able to do and stimulates higher order thinking (Alagic, 2003).

Modules designed for this project, by their very nature, include the use of technology to help students understand the underpinnings of the mathematics. As web-based activities, they incorporate the use of computers as an important tool in learning quantitative skills. Modules will be designed so that students have access to multiple representations of an individual concept. We will also, whenever possible, make use of connections between multiple representations and the underlying mathematics by developing ways to use technology so that students can choose and develop the representation that makes the most sense to them.

4. Do in depth problems that last more than one day and revisit quantitative skills frequently.

Problem solving skills are enhanced when students are given sufficient time to think and work on problems (e.g., Thompson, 1985). Thompson (1985) argues that learning mathematics is essentially a reflective activity for students – giving them time to reflect and internalize is often necessary. Exercises that scaffold several concepts (students learn them just before they continue the problem) and can be completed over the duration of several days, give students the experience, reflection and repetition that is essential to learning important mathematical concepts (NAGT workshop participants, 2002). Students are also given the chance to take some responsibility for their own learning and to learn to make decisions about quantitative tasks (Barrows and Tamblyn, 1980; Oberlander and Talbert-Johnson, 2004). Additionally, quantitative skills that are revisited repeatedly encourage students to make connections between different parts of a course. Some quantitative skills recur numerous times in the same course; when students are made aware that they have already mastered a revisited concept, the students will be better able to transfer quantitative skills from one context to another.

Our modules will make use of this important tool for developing and expanding students' quantitative skills. Many geoscience contexts utilize the same quantitative concepts –the importance of these quantitative concepts can be emphasized by the repetition of their use. In addition, because our web-based modules can be worked through at the student's pace and at a time coonvinient to them, learners can take the time they need to reflect on the task at hand.

PROJECT DESCRIPTION

We envision implementing “the math you need, when you need it” programs that will allow instructors to include quantitative concepts in introductory geoscience courses without spending class time on mathematical instruction. We will design web modules that utilize the “good ideas” from mathematics education and can supplement the content of any introductory geoscience course. The addition of these modules to a concurrently running geoscience course will help to seamlessly blend geoscience content with important mathematical content in a single learning experience.

The modular nature of our project is critical to its success. The number of topics that could be covered in an introductory geoscience course is so broad that, in essence, every instructor teaches a different course, with a different set of geologic topics. Many instructors may feel that there is no room for increased quantitative content (Shosa et al., 2000). Nonetheless, most introductory courses have the same goal: to increase the scientific and quantitative literacy of students. Our project is designed to address the diversity of topics and lack of time for increased quantitative skills by creating modular units that can be transferred to a number of different topics in geology. Moreover, the idea that multiple topics in geology touch on the same quantitative skills will serve to reinforce the quantitative skills learned from the modules.

The project is designed to allow faculty to choose the quantitative skills (and associated geoscience topics) that are essential to their course. From those choices, the website will generate a pre-test based on appropriate skills, and students who show deficiencies on the pretest will be required to complete specific modules on those topics before the geoscience context is covered in the classroom. The capacity for self-paced study by the students who most need the review/instruction will be built into each module. The selective nature of the web-based resources is an important and unique characteristic for our project because it is targeted at large numbers of students with diverse skills as noted by the NRC (2003) "Evaluating and Improving Undergraduate Teaching in Science, Technology, Engineering, and Mathematics." Indeed, the modular nature of this project allows us to produce individual components that are tailored to be of maximum use to instructors.

The program that we propose encompasses four parts that are to be used together to aid instructors and students in increasing the use and application of quantitative skills in geoscience courses:

1. a pretest that determines mathematical deficiencies of individual students;
2. the completion (by appropriate students) of “the math you need, when you need it” web-based, self-paced quantitative skills modules focusing on those skills determined by the pre-test to represent deficiencies;
3. use and application of appropriate quantitative skills in class periods soon after the due date for completion of the module; and,
4. a post-test to evaluate the effectiveness of the modules in increasing students’ quantitative skills.

1. The pre-test

Because pre-assessment of students' mathematical abilities is crucial to running a concurrent mathematics web course, the web-based program will be designed to allow faculty to generate a pre-test based on the topics/quantitative skills they choose for their particular course. In order to develop custom pre-tests and web quizzes that are tailored to each instructor's needs and allow instructors to track student performance on quantitative tasks, we will use PHP, a client-side scripting language that can be embedded into HTML and MySQL, a free, open-source database that interacts easily with PHP. The content-based test is expected to be administered at the beginning of each semester to initially evaluate entering students' mathematical abilities and mastery of quantitative material used in an individual introductory geoscience course. The data gathered from these computer-generated assessments will also be critical to the evaluation of this project, as it will provide a record of the quantitative skills of students before exposure to the modules.

The numerical results derived from student completion of the pre-test will be electronically recorded and provided to both student and instructor. This information will determine the quantitative skills for which a given student is under-prepared, and will inform both student and instructor that a module covering that topic is required before a given date. Once the modules needed are determined, the instructor need not concern his/herself with the administration of the module; it is now in the student's hands. The project provides for the tracking of completion of modules by appropriate students with little effort by the faculty. Evaluative tests are graded by the program and, can then be submitted to the instructor. The instructor need only enter a grade for the module.

2. The Modules

The modules themselves are designed to supplement the existing course so that additional quantitative content can be included with no classroom time spent to assess and equalize the diverse abilities of students. We propose to build a series of stand-alone modules based in essential quantitative skills for introductory geosciences. The application of mathematics to geoscience is key to the success of these pages; thus, all examples in the modules will be rooted in geoscience.

We anticipate making dozens of modules designed to cover the range of skills with which introductory students struggle. Many of the topics will be based on our own experience and the results of faculty surveys administered by SERC at national meetings of GSA and AGU during the past 2 years. Examples include but are not limited to:

- Percentages
- Distance/Rate/time problems
- Scale/scaling
- The metric system
- Unit conversions
- Density
- Large numbers
- Scientific notation
- Reading unusual graphs and diagrams
- Recurrence interval
- Density and specific gravity
- Calculation of gradients
- Sources of error and propagation of error
- Residence time
- Histograms
- Average (mean), median, mode

Three interconnected sections will comprise each module: 1) introductory material with instructional information, 2) sample problems (self-graded tests) and 3) an evaluative exit exam.

Introductory Material and Instructional Information

The introductory part of the module will contain the bulk of the purely mathematical side of a given quantitative concept. This front page will be used to present a single quantitative concept and to instruct students in the manipulation and application of that concept. Background material on the mathematics will serve to introduce the topic and a list of relevant geoscience topics that utilize the quantitative skill and background on those topics will be included. Finally, the greater part of the page will be devoted to ways to apply the mathematical concept to geologic problems. In this part of the module, students will find guidance in the quantitative concept, such as solved problems, tips, and other instructional materials. Each introductory page will be designed to help students to develop a deeper understanding of the concept.

Sample Problems (self-tests)

The introductory page on the quantitative concept will be linked to multiple pages designed to apply the mathematics to specific geologic topics covered in introductory geoscience. Because individual mathematical concepts are often used in multiple geoscience topics, we will design this portion of the modules to include multiple pages with 6-8 problems (with answers) based in a given geoscience theme. Individual pages that link from the instructive page can be pre-selected by the instructor so that sample problems address only the topics that are covered in class periods following the due date of the module.

The sample problem pages are designed to be self-tests – problems to be worked through by the student with answers (and process) provided. Self-tests will allow students to test their mastery of material by attempting problems on their own. Answers to self-tests will be provided so that they can check their answers for completeness and correctness.

Evaluative exit exams

Ultimately, upon student completion of the self-tests, the module will administer a final exit exam (similar to the self-test but without answers). Students complete this exam by filling in calculated answers and the web site grades their answers. When they have completed the test, students can print or forward their exam to the instructor to provide evidence of mastery. Successful completion of this exam provided to the instructor will be seen as mastery of the concept and the instructor need only enter the grade forwarded to him/her.

3. Application of quantitative skills in the classroom

The successful application of quantitative skills to geoscience problems as a regular part of an introductory geoscience course is an essential part of this project. In order to effectively convey quantitative skills, faculty must not only require student completion of the appropriate modules but must expect students to apply them to multiple situations in the classroom. Good ideas from the mathematics education community suggest that multiple representations and review of concepts multiple times are effective ways of teaching quantitative skills to undergraduates. These modules provide a means to get the students up to speed on the mathematics but the instructor is responsible for making sure that application is consistent in the classroom.

4. The post-test

A post- test (identical to the pre-test) will be administered at the conclusion of the course to evaluate the effectiveness of "the math you need, when you need it" modules in helping students master and apply quantitative concepts. The results will be a clear measure of the impact of this project on quantitative skills mastery.

Impact on undergraduate education

"The math you need, when you need it" addresses several challenges to effective undergraduate STEM education (NRC, 2003). Its modular design, flexibility, and stand-alone qualities will be particularly helpful for courses with large enrollments and when teaching students of diverse and varied backgrounds. The unique aspects of our project will allow faculty to easily adapt courses to students' preexisting knowledge of quantitative skills. Faculty will also have an easier time monitoring student progress because students can be expected to self-assess based on their performance on all parts of the program. Furthermore, by enabling clear and specific pre- and post- class evaluation, it will improve assessment of learning outcomes.

THE UNIQUE NATURE OF THIS PROJECT

Although there are many sources of mathematics help available on the web, our web-based resources are unique because they are designed to allows introductory students to explore difficult mathematics in the context of geoscience at their own pace. They address a need for the recognition that students, early in their academic careers, learn best when they have context for a new quantitative concept, representations that address a multitude of learning styles, and time to process what they have learned. In addition, application of new concepts in context not long after processing will help to solidify learning. Although many of the skills involved are those that students may have encountered in the mathematics curriculum, we will explicitly apply those skills to geologic examples to emphasize the importance of mathematics in geology.

In addition, the project addresses the importance in recognizing differences in the delivery of quantitative concepts to students. The presentation of mathematical topics in a geoscience class often differs markedly from mathematics classes. Vocabulary may be different, applications are stressed and representations may confuse students. Terminology presents difficulty for students familiar with mathematics. For example, what a mathematics professor would call "unit conversions", geology faculty may label "dimensional analysis" or "unit analysis". Mathematics courses may stress the manipulation of equations with little or no application for the mathematics; geologists rarely perform mathematics without an application. When students are asked to use and manipulate equations for application to geological problems, they may not know how to transfer the skills from manipulation to application. One of the most difficult aspects of quantitative skills in geoscience is the visual aspect of our science. To better understand time and depth relationships, we often turn visual representations of our science on their sides. Without explanation, this new way of representing data may confuse students – the invariant axis is now x! The difference in discourse (words, tools, representations) across disciplines presents barriers for students' transfer of knowledge across disciplines (Evans, 1999; Ganter & Barker, 2004).

Whereas there are many learning resources available to students grounded in theoretical mathematics, there are few available resources for students wanting to learn about applied mathematics and fewer still that deal with math in a geoscience context. For effective learning to take place, it is essential that students are shown the importance of quantitative applications in the appropriate context (in our case, a geoscience context). Geomaths at University College London (http://www.ucl.ac.uk/Mathematics/geomath/) is the sole student-oriented web resource for geological applications and provides excellent module-based learning for upper level students struggling with mathematics required in their courses. In addition to the links between upper level geoscience content and the mathematical skills needed, the site contains a "revision section" to help students to attain the appropriate mathematical level for these upper level courses. However, the "revision section" does not link the remedial skills to relevant geoscience topics as the upper level sections do. Although students enrolled at UCL can take an "Exit Quiz", there is no suitable universal access to self-tests or quizzes that can be evaluated by the instructor. Our project, geared at introductory levels with appropriate content linked to the mathematical concepts, will include the ability for students at any institution to self-test and evaluate their mastery of quantitative skills on their own. As discussed above, the ability to send the results to an individual's professor/instructor (at any e-mail address) is one of the important and unique aspects of this project.

USING CURRENTLY AVAILABLE RESOURCES

Existing faculty resources for teaching quantitative skills

This project will strengthen the efforts of the Science Education Resource Center (SERC) to support faculty in teaching quantitative skills more effectively. In that NSF supported project, Baer, Wenner and others developed web pages and collected and cataloged resources in order to assist faculty in teaching quantitative skills more effectively in introductory geoscience courses (Wenner et al., 2005). The proposed project continues and expands these efforts by developing pages that facilitate faculty inclusion of quantitative concepts by providing support to students with a wide variety of mathematical backgrounds. For instance, a faculty member may want to utilize resources about graph reading found on the Quantitative Literacy site at SERC but finds that a portion of his/her class lacks preliminary skills needed. The faculty member could require those students who do not have the skills to complete the appropriate "the math you need, when you need it" modules before he/she begins that unit in class.

The proposed project will round out a complete set of resources that is aimed at helping faculty to effectively teach quantitative skills in introductory geoscience courses. Whereas previous support provided training for geoscience faculty to apply lessons learned from mathematics education research, the proposed project will contribute web-based resources to support students in more quantitative geoscience courses. The resources will be developed in the context of the lessons learned and will provide a way for faculty to incorporate these quantitative concepts into their classroom more easily and with less disruption.

Web infrastructure supported by SERC

Carleton College's Science Education Resource Center (SERC) will host the modules through a dedicated portal on their own web servers. SERC's web infrastructure provides robust, high speed service using proven technologies supported by nightly off-site backups, custom configured local firewalls, diesel backup power, and professional server configuration. The SERC servers connect to the Internet through Carleton's redundant high-speed fiber infrastructure including full Internet2 access and are monitored from off-site to ensure continuous availability. Servers at SERC have proven to be highly reliable, comfortably handling traffic in excess of 11,000 visitors/day while maintaining an 'uptime' of over 99.7%

The proposed site will be built using SERC's existing content management system (CMS; Fox et al., 2005), which provides for the rapid development of content-driven web pages and searchable collections of resources and activities. SERC's CMS also includes a full suite of standards-based digital library tools integrated with the DLESE and NSDL collections and embedded within a larger environment. This infrastructure currently underpins over 3000 pages of original content written by more than 70 authors. In addition, he CMS is the basis for websites supporting over a dozen science education programs including the websites for National Association of Geoscience Teachers, the Cutting Edge Workshop Series, DLESE Community Core Services and several for NSDL (e.g., Starting Point, Earth Exploration Toolbook, and Microbial Life Educational Resources).

Widespread dissemination via the Internet

Use of the infrastructure at SERC will also ensure both permanence and broad dissemination of materials. Carleton College houses the Science Education Resource Center (SERC) and is committed to maintaining the web server, content management system, and bandwidth needed to support the site as long as the SERC is in operation (see letter of support). We will continue to work with Carleton to update pages/modules as necessary. We will also collaborate with the San Diego Super Computing center to ensure our site is archived as part of the NSDL library. Metadata records are harvested by DLESE and the NSDL and are thus archived for the foreseeable future.

Because SERC's website receives over 11,000 visitors per day (Manduca, pers. comm., 2006), publication on the site assures rapid and widespread dissemination of materials we create. Baer and Wenner's recent work on the Teaching Quantitative Literacy website illustrates the significant number of geoscientists who will potentially be reached through this important venue: During the month of November 2005, a single page on teaching radiometric decay quantitatively (Wenner, 2005) was visited by 2800 unique users (Manduca, pers. comm., 2006). Modern students and faculty find that the universal access and ease of website use provide a means to almost instantaneous satisfaction. The ability to track the users of our website allows us to understand some of demographics of those who use our resources and to begin to cater to those users.

In order to develop custom pre-tests and web quizzes, we will use PHP and MySQL, a free, open source database. Baer has experience with PHP and MySQL as they are already in use at Highline for other purposes; thus, no additional expenses or server-side problems should be encountered in using these tools. These tools are widely used and function on nearly any platform, so instructors at other institutions will be able to modify our resources for their own purposes.

BUILDING COMMUNITY

We will develop our resources in consultation with numerous other faculty and both in the geosciences and related fields. As geoscientists interested in education, we have built many contacts in the geoscience education community, through our work with SERC, at NAGT workshops and in conversations at professional meetings. These connections will be invaluable in developing these resources. We will likely draw those who test the modules in their courses at other universities from our own connections in the geoscience education field.

Through our work on Quantitative Literacy at SERC, we have begun to build connections in the mathematics community as well. In particular, we have collaborated with mathematicians who are interested in developing applications for mathematics and attracting students to the mathematical aspects of science. Thus, we will draw on previously developed relationships with mathematics faculty through workshops, our work at SERC and interactions at our home institutions (Highline Community College and University of Wisconsin Oshkosh) to help us unite the best of mathematics instruction techniques and training of geoscience students in quantitative skills. At our home institutions and through collaboration with SERC, we have begun to lay the groundwork for collaboration between mathematicians and geoscientists. At Highline Community College, mathematics faculty helped the geoscience faculty develop the MathPatch program by reviewing and recommending useful materials. At Oshkosh, geoscience and mathematics faculty collaborated to develop a “problem-based inquiry seminar” that combine mathematics and geoscience and is geared toward incoming students. Both interactions have been invaluable, serving to identify divergence in mathematics and geoscience vocabulary and providing ways to relate geoscience materials to standard practices in the mathematics curriculum. At Carleton College and at SERC, Baer and Wenner have built connections with mathematics faculty who have reviewed materials for the Quantitative Literacy website developed by Wenner and Baer in association with SERC. We expect that these helpful relationships will continue to be productive as we work with both mathematics and geoscience colleagues to incorporate current pedagogical thinking in mathematics into the modules proposed for this project.

OBJECTIVES AND BROADER IMPACTS OF PROPOSED WORK

This project has several objectives that will contribute to the goals of supporting student quantitative learning and increasing faculty comfort with teaching quantitative content in their introductory geoscience courses.

The objectives for this project are:

- Production and use of 30-40 “the math you need, when you need it” modules
- Improving introductory geoscience students’ mastery of, and comfort with quantitative skills.
- Increased retention and student success in introductory geoscience courses
- Facilitating the addition of more quantitative materials in introductory geoscience courses.

The proposed work is designed to have broad impacts on faculty in the geoscience community, particularly on those interested in increasing the quantitative literacy of their students. In addition, the proposed work will have an impact on the country’s citizenry as a whole by increasing the quantitative literacy of many students. Inclusion of undergraduate students at two- and four-year institutions will provide the students with opportunities that are vital to being an informed citizen. The skills that undergraduates build in courses such as geoscience are important in their future life (even outside the geosciences), a quantitatively educated introductory geology student will have developed scientific and critical thinking skills that are essential to being a productive citizen in today’s society. Furthermore, because the proposed study has implications for both mathematics and geoscience curricula, the broad dissemination of results is essential and we anticipate publishing it in education journals that appeal to a broad audience. Additionally, presentations at meetings (including possible participation at mathematics education conferences) and in other venues are essential to the success of this project.

OUTCOMES AND EVALUATION

Project evaluation focuses on three outcomes: (1) the production and use of the modules in geoscience courses, (2) student performance in modules and in geoscience courses, (3) faculty comfort with the addition of quantitative content of introductory geoscience courses. Formative assessment of the project will rely on quantitative and qualitative measures of these outcomes in the form of pre-and post-module data collection, walk-throughs, surveys and interviews. Feedback from this assessment will be used to modify our product during the development phase of the project and as summative feedback for final project evaluation.

Burn will be the primary evaluator of this project. She is a mathematics instructor at Highline Community College who is nearing completion of her Ph.D. in higher education from the University of Michigan. She has experience conducting evaluation research and is a powerful resource to ensure effective and valid evaluation and assessment of our project and the impact on student's quantitative skills. Burn's role will be to gather formative assessment data by observing student volunteers as they navigate the modules and resources developed as part of the project in order to identify usability problems and effectual impacts. Baer and Wenner will use that information to make appropriate changes to the modules and other project tools.

Production and use of the modules will be a tangible outcome. Thirty to forty modules geared toward preparing geoscience students to succeed in a quantitatively rigorous course will be universally available to instructors and students on the SERC website (http://serc.carleton.edu). Usage statistic programs on the websites that house these materials will track the use of web resources and will help us to characterize both faculty and student use of these resources. Usage tracking software is available as a part of SERC and documents the number of unique users, time spent on each module, portions of the module accessed (*e.g.,* self-tests or evaluated tests) and performance on individual tasks. In addition, tracking software will be used to formatively assess the use and effectiveness of the modules, providing us with further information about ways to modify the modules.

In assessing performance in the geoscience course, part of our second evaluation focus, we will compare attrition rates and student performance on quantitative exam questions in courses both pre- and post-implementation. We will also determine improved mastery of quantitative skills by comparing student performance on pre- and post-tests administered to students at Highline Community College and UW Oshkosh (and later at other schools). We will compare data gathered from courses that implement the modules to baseline data collected from courses in which the modules were not used. While the comparison of classes over time may not be perfectly valid in all cases (Moskal and Leydens, 2000) we will be able to examine impact of the modules on student performance easily. In addition, each module contains a post-test. This will provide us with aggregate data about mastery of quantitative skills.

The final outcome, facilitating increased quantitative content of geoscience classes, will be measured through interviews with instructors and examination of class materials used in pilot classes. We will interview faculty to determine the ways in which modules impact their teaching, whether they perceive a difference in students' quantitative skills and whether student attitudes toward mathematics were improved. We will design our interviews to determine the connection between the modules mapped and what was taught in the classroom, and whether instructors felt that they incorporated more quantitative skills in their courses with the use of these resources. We will examine course syllabi, exams, and other materials used before and after the project is implemented in order to further explore the impact of these modules. Finally, we will also determine the commitment of faculty to further increasing quantitative skills with the use of these student resources.

BROAD DESIGN OF ACTIVITIES

This project will take three years to complete. Work by both Baer and Wenner with SERC as Editors of the Teaching Quantitative Skills in the Geoscience website indicates that the writing of web resources averages about one page every 1.5-2 weeks of FTE. In the first year, we will identify 8-10 specific modules to be created and work toward recruiting faculty willing to test them. In addition, early in the project we will gather "pre-module" data on quantitative skills at universities there the project will be tested. Once topics are identified, much of the time in the first semester will be spent creating these pilot modules (Wenner will generate 2-4 and Baer will generate 4-7). Once the pilot modules are created, efforts will be focused on testing the modules in classroom situations. During this implementation period we will monitor student use and mastery, interview faculty, and evaluate through pre- and post-testing to analyze whether student abilities in applying quantitative skills have increased. As we receive feedback on the results of testing, we will modify modules as necessary

In the second year, we will continue to test pilot modules and to conduct interviews, observations and post-assessments. The initial testing period (in the first year) will clarify effective ways to use the materials in a variety of introductory courses, document any barriers to use or implementation, and allow us to make adjustments to the modules in order to improve effectiveness. The results of interviews and other assessment techniques will also serve to guide us as we modify existing resources and begin to develop other modules.

In the third year, testing of modified pilot modules and those we develop in the second year will continue. Our focus in this year is to identify any barriers to more widespread application of these new curricular materials by expanding the schools at which they are being tested. We will also interview faculty to determine how the student resources are allowing them to increase the number and rigor of quantitative exercises and skills used in their geoscience courses. Finally, we will compile and compare rates of student success and retention to evaluate whether we can measure positive results that are in line with those of the MathPatch program at Highline.

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