Collaborative Research: Expansion of "The Math You Need, When You Need It" Through Widespread Implementation

PIs: Eric Baer, Highline Community College and
Jennifer Wenner, University of Wisconsin - Oshkosh
Co-PI: Helen Burn, Highline Community College

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PROJECT SUMMARY
COLLABORATIVE RESEARCH: EXPANSION OF "THE MATH YOU NEED , WHEN YOU NEED IT" THROUGH WIDESPREAD IMPLEMENTATION

PIs: Eric Baer, Geology Program, Highline Community College and Jennifer Wenner, University of Wisconsin Oshkosh, Oshkosh, WI; **co-PI:** Helen Burn, Mathematics, Highline Community College

Intellectual Merit: This project directly addresses the need for student-centered resources that support quantitative skills inclusion in introductory geosciences courses. The project includes the goal of increasing the quantitative content of introductory geosciences courses given the many opportunities these courses provide for increasing the quantitative literacy (QL) of students, particularly general education students. However, in attempting to reach this goal, faculty can face significant challenges due to students' varied mathematical preparation and attitudes towards mathematics.

The proposed project has 2 objectives: 1) to develop a variety of implementation models for the use of TMYN through program expansion and 2) to facilitate the teaching and learning of quantitative skills in the geosciences. Both objectives grew out of the successful piloting of our CCLI Phase 1 project *The Math You Need, When You Need It* (TMYN) modules in several courses at our own institutions. TMYN are self-paced, web-based student modules that support teaching and learning of quantitative topics in introductory geoscience. Pilot projects at University of Wisconsin Oshkosh (UWO) and Highline Community College (HCC) have been highly successful and combine several proven pedagogies: Student centered instruction, online modular resources and Just-in-Time Teaching. The varied ways in which instructors at UWO and HCC implemented web resources suggest that these can be useful at numerous institutions. Furthermore, positive student achievement and attitudes when these modules are used indicate that these are effective ways to remediate mathematics skills for general education students.

With the successes realized during implementation at our institutions, we propose to explore the effectiveness of these modules by training faculty in their versatility and working with interested faculty to design effective and innovative implementation models. In addition, we anticipate developing 6-10 additional modules so that we have a collection of roughly 14 to 16 quantitative concepts that will be useful to the widest variety of geoscience courses possible. The project will result in a large dataset and web-based resources related to the teaching and learning of quantitative skills in introductory geosciences courses. Participants in the expanded TMYN program will build resources related to teaching that could make this project self-sustaining.

Broader impacts: This project has broad implications for increasing QL in the undergraduate population as well as in the educated citizenry of the US. Increasingly, colleges and universities are recognizing QL as an important outcome for their graduates to become integrated into our increasingly number-oriented society. The modular design of TMYN allows for tailoring to individual courses and can support increased QL for the more than 350,000 students that take introductory geoscience every year (Martinez and Baker, 2006). 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. Through several workshops and development of web pages that detail the results of the use of TMYN modules at many different institutions, we will support faculty in developing effective methods for teaching QL and create a large (35-40) cadre of instructors who have experience and leadership in the use of QL in the classroom. Use of the increasingly popular SERC web server will ensure nearly instantaneous widespread dissemination and ready application at a variety of institutions. We anticipate creation of a self-sustaining tutorial in the use and implementation of TMYN for any one to use. 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, 2003).

COLLABORATIVE RESEARCH: EXPANSION OF "THE MATH YOU NEED , WHEN YOU NEED IT" THROUGH WIDESPREAD IMPLEMENTATION

INTRODUCTION

This project seeks to expand the successful use of the NSF-funded CCLI Phase I project "The Math You Need, When You Need It" (TMYN) in conjunction with introductory geoscience courses. Over the course of the exploratory Phase 1 project, the PIs developed a series of web-based, student-centered modules that support teaching and learning of quantitative skills (http://serc.carleton.edu/mathyouneed). The PIs also coordinated successful module use in three different geoscience courses at their institutions, developing appropriate implementation models for each of the courses. Results at University of Wisconsin Oshkosh and Highline Community College show that most students improve their quantitative skills with use of the modules and feel that TMYN provides the support and review they need to succeed in their introductory geoscience courses. In addition, faculty response to the modules has been positive overall – the relatively painless support provided by these on-line resources empowers instructors to use quantitative skills in their courses without giving up valuable class time.

With the proposed expanded project, we seek to increase faculty expertise in the use of TMYN and encourage increased inclusion of quantitative skills in introductory geoscience. The successes at our own institutions and conversations at workshops and conferences suggest that institutions that contrast and complement our own are also interested in increasing the quantitative skills of their students. The proposed project will bring together faculty at diverse colleges and universities to explore a variety of successful ways to implement TMYN modules. TMYN expansion efforts include faculty development opportunities through training and syllabus redesign, implementation of pedagogically sound educational innovations, and the creation of online learning materials that will increase student achievement in introductory geoscience courses. One goal of the proposed project is to support the myriad models of implementation and to impact a large number of the more than 350,000 students who enroll in introductory geoscience each year (Martinez and Baker, 2006).

Implementation models will be designed by some of the more than 65 institutions that indicated that they were interested in helping us test our successful online mathematical support materials. One goal of the proposed project is to, at the end of four years, have a diverse set of up to 40 institutions, with variations in institution type (e.g. public/private; research/teaching,) size, student population, ACT/SAT scores, admission statistics, etc., who have successfully implemented TMYN in conjunction with introductory geoscience courses at their institution. With the guidance of the PI's, groups of interested faculty will become experts in using these resources. Our cohort of implementers will identify appropriate contexts for the inclusion of quantitative skills in their courses, assess student achievement − including both formative and summative assessments − and develop models for implementation at their own institutions. Implementation of TMYN at a number of institutions will help us to understand the versatility of this important resource and allow us to explore what makes the modules successful. In addition, the results of this project will contribute to research on effective use of online support materials to remediate skills in introductory science courses.

Opportunities, Desire, and Need for QL in the Geosciences

Due to a recent push by the Association of American Colleges & Universities to focus on Liberal Education reform [including quantitative literacy (QL)] at the collegiate level (LEAP, 2008), many colleges across the country have begun to modify their general education programs to include QL (e.g., Bressoud, 2009). These newly formed programs are important opportunities for geoscience educators to: 1) take advantage of curricular modifications by including quantitative skills in introductory geoscience; 2) educate the general population (particularly math phobic students who tend to self-select into general-education geoscience courses) about the role that numbers and mathematics play in every day life; and 3) increase the number and preparation of qualified majors by accurately representing the geosciences as data-driven and quantitative in nature.

Over the past decade, there has been a move in the geosciences to increase the quantitative nature of courses that students encounter (e.g., Macdonald et al., 2000; Powell and Leveson, 2004, Manduca et al., 2008; Wenner et al., 2009). In contrast, since the 1970's, introductory geoscience textbooks have become distinctly lacking in quantitative content (e.g., Shea, 1990), despite the recent finding that mathematical background is one of the most important indicators of success in introductory science classes (Sadler and Tai, 2007). Non-quantitative treatment of geoscience in textbooks reinforces the stereotype of the introductory courses as "rocks for jocks" and can present faculty with significant resistance to including quantitative content in their courses. Resistance comes from a number of sources, including students, administration, and even other faculty members. Students who self-select into introductory geoscience to fulfill general education requirements often indicate that they did so because they thought it was the least mathematical option; examination of the textbook would suggest that their perception is accurate. Lack of textbook support can lead instructors to gloss over the mathematical and data-rich nature of the geosciences and the paucity of mathematical support has led to a variety of workshops and meetings designed to help instructors to support the inclusion of QL in geoscience courses (Manduca et. al, 2008). From 1999 to 2006, NSF sponsored five workshops designed to help over 125 attending geoscience and mathematics faculty members to develop high-quality quantitative exercises appropriate for all levels of geoscience courses (see http://serc.carleton.edu/quantskills for links to all of these workshops).

The move to bring quantitative skills to students in introductory geoscience courses has led instructors to uncover new obstacles to student learning. Given the widespread perception that the geosciences are non-quantitative, general education geoscience courses commonly draw students with pervasive math anxiety/avoidance/phobias (e.g., Manduca et al., 2008). Mathematics preparation among introductory students can range from minimal high school math to higher levels of calculus and even students with significant theoretical grounding in mathematics may struggle with transferring and applying mathematical techniques in specific contexts [a common problem in other STEM disciplines such as chemistry and physics (*e.g.,* Bransford et al., 1999; Cerreto et al, 1977; David, 1990.)] Thus, geoscience instructors may wrestle with the level at which to present mathematics: do they teach to the lowest level, and possibly lose many promising students, or assume mathematics knowledge and leave struggling students behind? Bringing online "just-in-time" support of quantitative skills in the geosciences may help to level the playing field for both student and instructor. The proposed project to bring TMYN modules to more classrooms is designed to increase quantitative content in geoscience curricula across the US and facilitate the teaching and learning of quantitative skills in introductory geoscience courses.

BACKGROUND AND UNDERLYING PEDAGOGY

The PI's interest in quantitative skills in the geosciences began with work on Teaching Quantitative Skills in the Geosciences (http://serc.carleton.edu/quantskills/), a website that supports faculty in the quantitative teaching of the geosciences. Each page on this site uses best practices in teaching college-level mathematics in the context of the geosciences (e.g., Steen, 1988; Schoenfeld, 1992; AMATYC, 1995; Anderson and Swanson, 2004; Manduca et al., 2008; Wenner et al., 2009). This collection of activities, workshop programs, syllabi, and teaching techniques provides instructors with classroom-tested, peer-reviewed ideas for incorporating QL at all levels of the geoscience curriculum. Nonetheless, our own experience and formal and informal conversations with colleagues indicate that successful incorporation of mathematical techniques in a geoscience course requires more than instructor support. More specifically, student support and supplemental instruction are needed if students in our courses are to become more quantitatively literate.

MathPatch- Success when support is provided

At Highline Community College, approximately 85% of students enter with mathematical abilities below intermediate algebra (B. Maplestone, pers. comm., 2006), and many students are unable to complete even simple quantitative tasks. Recognizing the need for student support and supplemental instruction, Highline's math and geoscience faculty developed a one-credit course (colloquially named MathPatch) to be taken concurrently with Geology 101 (Physical Geology). Requiring students with poor math skills to enroll in MathPatch significantly reduced attrition and failure rates in Geology 101 (Baer et al., 2002). Prior to the implementation of MathPatch, 27% of students dropped Geology 101; when MathPatch was mandatory, attrition decreased to 16%. Average student performance in an individual instructor's sections improved from 73% (without MathPatch) to 81% (with MathPatch) (Baer et al., 2002). Furthermore, since the incorporation of MathPatch, faculty are assured that students are to be competent in quantitative concepts and have increased the quantitative content of geology courses accordingly (Baer et al., 2008).

Student-Centered Instruction and Just-in-Time Teaching

MathPatch and TMYN are derivatives of several widely tested and proven pedagogical innovations: student-centered instruction (SCI), modular support materials and Just-in-Time Teaching (JiTT). In SCI, students are made responsible for their own learning and hence are more motivated, have greater retention rates, and approach learning more positively (McKeachie, 1986; Bonwell and Eisen 1991; Johnson, et al., 1991; Meyers and Jones, 1993; Felder and Brent, 1996). Research suggests that when student-centered instruction is modular in nature, students are more likely to succeed in STEM disciplines (e.g., Russell, 1974; Comer, 1996; Reed, 2001; Elaine, 2002; Weintraub and Martineau, 2002). With JiTT, students prepare for active participation in the classroom by completing exercises on the web (e.g., Novak and Middendorf, 2004; Novak et al., 1999). TMYN modules are student-centered, modular in nature, and designed to present quantitative material "just-in time", with students learning and being quizzed on the material just before they need to apply it.

RESULTS FROM PRIOR NSF SUPPORT

ERIC M. BAER: COLLABORATIVE RESEARCH: The math you need, when you need it: Modular student resources to encourage successful incorporation of quantitative concepts in introductory geoscience, DUE- 0633755, 2006-2009, $131,358.

JENNIFER M. WENNER: COLLABORATIVE RESEARCH: The math you need, when you need it: Modular student resources to encourage successful incorporation of quantitative concepts in introductory geoscience, DUE-0633402, 2006-2009, $68,629.

To address both teaching and learning issues associated with the inclusion of quantitative skills in introductory geoscience courses, we built and tested a series of web-based, self-paced modules - *The Math You Need, When You Need It* (TMYN) - focused on reviewing and reinforcing quantitative skills that students will use in their introductory geoscience course. Design and topics for web modules grew out of discussions with colleagues at other institutions and the results of a faculty survey conducted on the newly designed site (http://serc.carleton.edu/mathyouneed/index.html). With TMYN, students complete the three-pronged modules (explanation, sample problems and final assessment) just before they encounter quantitative content in a geoscience course. While working through the modules, students are shown how quantitative concepts (such as trigonometry, graphing and unit conversions) connect to multiple geoscience contexts that students might encounter in the associated course. The goal is to motivate students and provide opportunities to develop or review specific mathematical techniques just prior to applying them in the geoscience classroom. We also include information for instructors on a separate but easily accessible page. The modular nature of the project allows instructors to choose specific quantitative concepts that are appropriate for an individual course. To date, there are 8 modules that were tested in three distinct courses at Highline Community College (Physical Geology) and University of Wisconsin Oshkosh (Physical Geology and Environmental Geology). Many of the pages were peer reviewed for appropriateness of content and design by 2-3 evaluators and 5 of the 8 were evaluated by the CCLI phase I evaluator (Burn) using a framework for multimedia learning developed by Mayer (2001).

Instructor response – Survey information

Presentations of early versions of the website at professional meetings led to vigorous and encouraging discussions with faculty about the desperate need for this type of modular mathematical tutorial. Because we were interested in the types of modules that would be most useful to instructors, we designed a survey that asked geoscience faculty to indicate the topics that were most important or relevant to their introductory courses from a list of 31 topics. Faculty indicated that they might use anywhere from 7 to all 31 of the topics in their courses. The four most popular selections were: (1) graphing (n=65), (2) unit conversions (n= 62) and (tied for 3) linear plots and rates (n=55).

On this same survey, we included a place for respondents to indicate whether they would like to help us test TMYN modules in their classes. The overwhelmingly positive responses to the survey led us to design this expansion project. All told, nearly 100 people responded to our survey, with 65 indicating that they were interested in testing the modules in their own classes. Positive responses for our call for module testers came from every institution type, including R-1 institutions (e.g. University of Massachusetts and Tulane), private liberal arts institutions (e.g. Carleton and Trinity Colleges), comprehensive state universities (e.g. California State University

– Chico and Northern Illinois University) and community colleges (e.g. Central Wyoming and Wake Tech C.C.). Even two high school teachers expressed interest.

Website design

Over the course of the CCLI Phase I project, we designed 8 individual modules for student use: calculating density, plotting points, best-fit line, hypsometric curve, rearranging equations, slopes, trigonometry, and unit conversions (see http://serc.carleton.edu/mathyouneed). The modules have three student-centered pages and an instructor page. When a module is assigned, students work through the pages sequentially, moving from an explanation of the mathematics to sample problems and culminating in an online assessment. The design is an outgrowth of our own experience, the faculty survey, and conversations with both geoscience and mathematics faculty members about what students need to succeed.

Explanation pages: Each module has a student-centered mathematical topic page that outlines several aspects of an important quantitative concept as applied in the geosciences. Each explanation page contains an introduction to the mathematics behind the concept, with information about why a student might need to understand this concept. If appropriate, we include steps/an algorithm that a student can follow each time s/he encounters this concept in her/his geoscience course. In addition, we address questions students may have about the use of the concept, including "Why should I be able to do this?" "Where is this used in the geosciences?" and "Where can I get more help?" Conceptually, we would like to provide students with motivation and a framework from which to address mathematical issues throughout the geosciences.

Sample problem pages: Explanation pages lead directly to a second page of sample problems. The sample problems are drawn from 3-4 geoscience contexts in which students may encounter the relevant mathematical concept. For example, the rearranging equations module has sample problems that deal with velocity, density and isostasy; the plotting points module has solved examples using plate motions, discharge and elevation data. Answers to each sample problem, using the algorithm on the explanation page, are provided but hidden to encourage students to attempt each step on his/her own. At the bottom of the sample problem page, students find links to more help on the web.

Online assessment: When students reach the end of the sample problems, they are directed to an end-of-module assessment. The online assessment is conducted using IMathAS, available on the Washington Mathematics Assessment and Placement website (http://wamap.org), a web-based mathematics and course management platform. This open-source, free course management system is a powerful tool that allows design of mathematical questions, including equations, plotting points and graphing. Because immediate feedback plays a role in improved learning (McKeachie, 1986), students are provided with correct answers to compare with their own once they have completed the quiz. The test bank includes a wide range of questions applicable to many introductory geoscience topics. We anticipate migrating the hosting of the IMathAS platform to SERC so that all parts of this project will be housed together and to ensure continuity of the assessment software.

Instructor pages: Each of mathematical concepts also includes a page for the instructor. Because we wanted all pages to be public, there is nothing on the instructor page that a student should not see. The instructor page is designed to tell the instructor what to expect: What students will get out of the module, why we think students may struggle with a given concept and what we may have left out of the module. We also provide instructors with some resources to learn more about the concept.

Implementation Models

During the fall of 2008, the TMYN modules were piloted in courses at Highline Community College and University of Wisconsin Oshkosh. Courses at Highline were taught by one PI (Baer) and another instructor; at Oshkosh module use was coordinated by Wenner and courses were taught by her colleagues. Because a different instructor taught each course, we ended up with three distinct implementation models. Our findings bear on the effectiveness of the implementation models, the use of modules by students, student attitude toward the difficulty and helpfulness of the modules, measures of student learning from the modules, and faculty attitude about the modules. Each of the implementation models was successful in its own way and the results and interpretation follow.

Highline Community College – Physical Geology plus Quantitative Geology

Highline Community College is an open-enrollment institution 15 miles south of Seattle, Washington. Highline's enrollment is nearly 17,000, 61% of whom self-identify as non-white. The Geology program at Highline consists of one full time tenured faculty (Baer) and multiple adjunct faculty who teach 5 different introductory level courses (in multiple sections) throughout the year. The geology courses at Highline are small (capped at 24-28) with lab and lecture taught by the same instructor.

Faculty at Highline implemented the modules in conjunction with two physical geology courses, each with 24 students. Use of TMYN at Highline was within the separate, one-credit MathPatch course. In spring 2008, the MathPatch course was only offered online. In fall 2008, Baer offered the option of face-to-face instruction and many students took that option. At the beginning of each quarter at Highline, the instructor administers a preliminary quantitative skills assessment to determine who needs mathematics review. Typically, one- to two-thirds of the students do not pass the assessment and are required to enroll in MathPatch. Students who enrolled in the face-to-face course did not complete the modules online.

At Highline, student completion of the modules was low in both spring and fall quarters. Although students were required to use the modules, few actually completed all of them. Instructors reported that students resented having to enroll in (and pay for) an additional course that not everyone is required to take.

UW Oshkosh - 2 implementation models

University of Wisconsin Oshkosh is a rural, regional comprehensive university with approximately 11,000 students and draws mostly from nearby communities, admitting 79% of applicants resulting a student body that is predominantly white (~92% self identify as such). The Geology Department at UW Oshkosh grants only Bachelor's degrees and houses 9 full-time faculty members. Seven faculty members teach geology at the introductory level. TMYN was used in two introductory geoscience courses at UW Oshkosh in the Fall Semester 2008: Environmental Geology and Physical Geology.

UW Oshkosh implementation model 1 –Environmental Geology: In the Environmental Geology course (taught by Dr. M. Muldoon), 180 students were asked to complete a written (in-class) pretest and three modules (slope, rearranging equations and unit conversions). Students were given credit for completing modules (and the pre-test) but were not graded on performance.

Historically, Environmental Geology has not included a large quantitative component and Advising Office staff members tell us that they direct math phobic/ non-science oriented students to take that course rather than the Physical Geology course. In Environmental Geology, the modules were introduced to the class at mid-semester, just before they began using quantitative skills in lab. Participation in TMYN in Environmental Geology waned significantly after the initial module was implemented. The instructor suggested that the late introduction of the modules, the general malaise in the class by that time in the semester and the overall lack of quantitative content before the middle of the semester contributed to the low participation. However, response from those who did complete the modules was generally positive (students thought they were helpful in both lab and the overall course) and most improved their scores over those on the pre-test. Furthermore, the instructor indicated that she spent less time in class instructing students in the appropriate techniques and believes that quantitative content in this course could be increased with support from a resource like TMYN.

UW Oshkosh implementation model 2 –Physical Geology: The instructor (K. Kramer) for the Physical Geology course began the course by administering a low-stakes (attendance credit) in-class pre-test to determine the abilities of the approximately 170 enrolled students. After the pre-test, she emphasized to the class that the TMYN modules would help them succeed in the course. She invited Dr. Wenner to talk to the class about the goals of the modules and instructors' desire for the students to succeed when faced with math concepts in a geologic context. In all, students completed 4 modules (unit conversions, rearranging equations, plotting points and best-fit line) during the semester and were given full credit for each module completed, without regard to performance. Each time a module was assigned, Prof. Kramer reiterated the importance of the modules to their success. Participation by students in Physical Geology remained high throughout the semester, approximately 80 % of the class (135 of 170 participated consistently) participated on the final modules (reintroduced after several weeks without an assignment. Furthermore, the overall response was positive to the use of these modules in the Physical Geology course; the majority (81 of 102) of responding students provided positive feedback about the modules' role in their success in the course. Lab instructors indicated that time spent in lab re-explaining how to complete quantitative concepts was greatly reduced (K. Kramer and C. Demosthenous, pers. comm., 2008). We believe that Prof. Kramer's enthusiasm and expressed desire for students' success contributed to the high participation rate and positive feedback

At UW Oshkosh, we observed excellent participation and positive student and faculty feedback when a limited number of modules were used as part of a class. This may be a successful model for this institution. Implementation did require one of the PIs (Wenner) to monitor and support both instructors and students and to deal with problems as they arose. However, it is unclear if the support was needed because it was the first time these instructors used the modules or if it indicates a need to adapt the modules to make them more self-supporting.

Implications for use, adaptation and implementation of the Math You Need

The results of piloting these modules at our institutions, although limited at this time, have several implications to explore further with the expansion of the TMYN program. Questions remain about how variability in class/institution size, instructor teaching style, implementation model, and student/faculty perceptions will affect the program. However, the varied nature of our three models provides insight into some of these things, particularly at our institutions:

Student navigation: Although faculty at both institutions were initially concerned that students would be confused by the use of two different websites (SERC and WAMAP), students seem to have little problem navigating through the assigned modules. Early observations of students at Highline led the PIs to create a relatively linear model for navigation – one in which the student works through a page, and a link at the end leads him/her to the next step. On an end-of-term survey, 5 of 8 students at Highline consistently expressed that the modules are easy to navigate.

Student perception: At the end of each post-module quiz, students were asked to rank their perception of the difficulty and helpfulness of each of the modules. At both Oshkosh and Highline, students thought that the modules that they took were helpful. This was true for all modules they completed, whether or not they found them difficult. Approximately 80% of student respondents (777 out of 962 total responses) were neutral, agreed somewhat or strongly agreed with the statement, "I found this module helpful" (Wenner et al., 2008). At the same time, only 30% (231 of 762) of respondents agreed that the modules were difficult (ranging from 8-60% depending on the module; Wenner et al., 2008). This is a positive result, suggesting that even students who feel they already understand a mathematical concept believe that the modules are helpful. Exploration of student perceptions will play an even more important role in the proposed project.

Student learning: For all courses that piloted the modules, the majority of students improved between pre- and post-tests. At Highline, all students who completed a majority of the modules showed improved skills between the pre- course evaluation and the post-module quiz. At Oshkosh, students in both piloting courses show improvement with the use of the modules. In Physical Geology, 92% (138) of the 150 students who completed 3 or more modules improved their scores over the pre-test (Wenner et al., 2008). Environmental Geology students improved but we found that scores increased for only 77% (92 of 120) of students who completed 2 or more modules(Wenner et al., 2008). Exploration of the variations that contribute to student learning (such as faculty buy-in, skills of students enrolled in the course, design of modules, etc.) will be an integral part of the expansion of the program to new institutions.

Grading stakes: One result of the pilot study is that the impact of the use of the modules on student grades did not to correlate with participation. Contrary to our initial perception of the importance of grading, courses in which students received a grade based on performance had lower participation rates than courses that applied grades based solely on completion. One of the goals of the expansion project is to explore possibilities for student evaluation and grading that will encourage students to participate but not get discouraged or frustrated by failure.

Faculty response: Responses from faculty at Oshkosh suggest that the experience of using TMYN with introductory geosciences courses is overall positive (Wenner et al., 2008). Instructors indicated that the time spent explaining mathematical concepts (particularly remedial concepts such as graphing and algebra) went down significantly. One instructor reduced the amount of time at the beginning of lab significantly because she could assume that students had encountered the material when they completed the TMYN module. The instructor of the Environmental Geology course (traditionally without much quantitative content) indicated that she felt more confident in modifying the in-house lab manual to increase the amount of quantitative material (and to reduce the "hand-holding" for the math). These responses and the positive attitude suggest that TMYN helps faculty to feel empowered to represent geoscience as the data-rich, quantitative sciences it truly is. Providing more support for faculty in this way will help to create classrooms where mathematics are expected and realistically represented, one of the goals of our proposed work.

Adaptation and implementation: Implementation of TMYN in these three distinct settings suggests that the modules are quite versatile. Although all three classes had variations in student body, enthusiasm of the instructor, timing, content and quantitative topics, all three were successful in one way or another. The successes of all three implementation models led to the current project. One main goal of the current project is to explore the implications of the pilot project and how the modules can be creatively implemented in a variety of situations.

PROJECT DESCRIPTION

The proposed project represents an expansion of *The Math You Need, When You Need It* program. One level of expansion involves implementation of the program in a variety of higher education settings, capitalizing on the successes of the pilot program and the demand for these modules from geoscience faculty across the country. The second level of expansion involves development and modification of TMYN modules to be used in the widest variety of geoscience courses possible. A large component of both of these expansion efforts involves formative and summative evaluation of the program to document effectiveness and to modify the program to be more effective.

Objective 1: Develop effective implementation models by expanding the TMYN program to a variety of institutions

The first goal of this project is to expand effective implementation of the TMYN program to up to 40 new and diverse institutions through faculty professional development, pedagogical support, and development and evaluation of innovative implementation models. The positive response from approximately 100 faculty members to our development of this resource indicates there is widespread faculty interest in increasing the quantitative content of introductory geosciences. Response to our survey indicates that interested instructors can be drawn from a broad range of institutions, from rural community colleges to urban universities, highly selective liberal arts colleges to open-door institutions and everything in between. As such, we intend to build a network of implementing institutions (and leaders therein) that demonstrate many variations on the theme of increasing the quantitative content of geoscience courses. Furthermore, results from our own piloting of the modules suggest that variations on the use and implementation of the resource are manifold and we may still not understand the range of models. Thus, we propose to train instructors at a wide range of institutions and introductory geoscience course types in the use of TMYN with the ultimate goal of generating new models for use and a self-sustaining training program that is web-based.

Design innovative implementation models: One goal of the previous (CCLI Phase 1) project was to develop a program that was useful in a wide variety of situations. Our pilot projects suggest TMYN is already a flexible program with a significant number of possible adaptations. Our own discussions with faculty at other institutions illustrate that variations on implementation could be infinite – each faculty member seems to have a different idea for how to adapt this so that it can be used at his or her institution. As a result, one outcome of this project is to demonstrate the range of possible implementation models and encourage a wide variety of institutions and geoscience faculty to use this important and effective resource.

One implication of the pilot studies at Highline and Oshkosh suggests that a large number of variables (from faculty engagement to class size and diversity to course and institution type) play a role in the success of the TMYN program. In other words, one size does not fit all. Even with the diversity of variations among the three courses in which TMYN was used in the pilots, TMYN proved adaptable and successful. We have designed this expansion project to bring together innovators in the teaching of quantitative topics in the geosciences to brainstorm and create new ways of adapting this pedagogical innovation. Ultimately, these innovations will be disseminated to the wider public through description of the model on a web page. New implementers of the program can use these pages as templates for their own innovations.

Faculty professional development and support: Faculty professional development is an integral part of this project. Our goal is to help faculty to 1) learn the strengths of this innovation, 2) examine their own teaching practice to identify suitable ways to increase quantitative content in introductory geoscience courses, and 3) design and evaluate innovative integration of TMYN into their own courses. Each year, a 1-2 day workshop will be held for TMYN implementers. The PIs will present the basic design and results from piloting the program and discuss the implications for student learning and faculty involvement. In small groups, the PIs and participants will examine syllabi and exercises used in each of the implementers introductory geoscience courses to identify possible application of TMYN. Once suitable modules are identified, the group will discuss possible implementation models, troubleshooting, and important variables to consider. The workshop will culminate in a plan of action for each course that will include: an implementation model with benchmarks for achievement, an outline of needed pedagogical and technical support, and desired outcomes for the faculty member and students. Burn, the project evaluator, will develop an evaluation plan for each new implementation, patterned after the evaluation model developed in the TMYN pilot (e.g., pre- and post-testing and student perceptions of utility and helpfulness of the modules) and adapted for any additional outcomes of interest within a specific implementation.

We envision the workshop evolving throughout the duration of this project. Because so many faculty desire to use these modules and use them as soon as possible, we have already identified several of the first cohort of implementers (see Letters of Support). The overwhelming survey response from such a diversity of institutions enabled us to identify a small group of institutions that complement our own (including a large research institution, a small liberal arts college, two small state schools and a comprehensive state university) for the first wave of implementations. In the first year, support for these institutions will be substantial on the part of the PI's. We will work closely with each of the implementers in their first year, modifying and improving the web resources based on their feedback. Travel support and a small stipend will be provided to the initial implementers on the completion of their project and the documentation of their results.

The second and third years of developing implementation models will involve 14-16 new institutions each year and input from the previous group. We envision gathering a group of previous implementers for a short (one-day) workshop to discuss the results of their implementation model and create a web page outlining the ins and outs of their model. Those previous implementers will then join the PIs in leading the next training workshop, beginning the following day and following an agenda similar to that outlined above. Our goal is to expand the number of both instructors using the modules, and faculty leaders to train others to in module implementation.

In the first 2 years of this proposal, the PIs will financially support participation by implementers through full funding of the workshop and stipends ($500-1000 per participant). We believe this is necessary in order to encourage faculty 1) to try a pedagogical innovation and 2) to complete the implementation and evaluation. In year 3, we hope that documented success of the program will inspire the new cohort to attend the fully funded workshop and complete the implementation without a stipend.

In the final year of project, we will use what we have learned from our three cohorts of implementers to build an online tutorial for adaptation of TMYN in a variety of situations. The online workshop tutorial will be modeled after the Online Course Design Tutorial already in place at SERC (http://serc.carleton.edu/NAGTWorkshops/coursedesign/tutorial/) and would employ the participant-built implementation model pages to guide new users in the use of TMYN. In this way, we hope to develop a self-sustaining model of expansion.

Objective 2: Facilitate the teaching and learning of quantitative skills in introductory geoscience

We created TMYN modules to support the infusion of quantitative skills throughout the introductory geoscience curriculum. Through the use of this important resource, students learn to use and apply mathematical techniques in a geologic context, often revisiting the same mathematical concepts in multiple real-world situations, hallmarks of quantitative literacy (e.g., Steen, 2001). The Math You Need and this expansion effort will support the teaching and learning of quantitative literacy by increasing the number of modules available to faculty and students, continually assessing and improving the effectiveness of these modules and their use, and by providing logistical and structural support for institutions using the program.

Design and write effective teaching tools for faculty: To facilitate teaching and learning, the expanded TMYN program will provide instructors with modules that they feel will be useful in their courses. To date there are 8 modules; however, the results of our survey indicate that 6-10 new modules (e.g., radioactive decay, rates, big numbers, etc.) would provide instructors with mathematical content appropriate for most introductory geoscience courses. Thus, part of the project is to write several effective new modules and to make current modules more effective for student learning.

The number and content of newly developed modules will be based on the results of our online survey and the needs of participating implementers. Each new module will follow the model of all other pages: an explanation page, sample problems, a culminating quiz and an instructor page. The PI's will be primary authors of these modules but anticipate significant input from participating faculty, particularly in regards to sample problems and quiz questions. We would like to tailor some questions to be most effective for our implementers. Furthermore, each new module will be blind peer reviewed for content and perceived effectiveness before we make it available to the public.

In addition to writing new modules, we will adapt existing modules to maximize effectiveness. End of module assessments in WAMAP are constructed so that we can measure both student learning (relative to the pre-test) and their perception of how the module affected their performance in the course. Students are also given the opportunity to give written feedback about any aspect of the assessment. From our experience, students are particularly helpful in providing feedback about the parts of the module that did not work. This kind of feedback can be extremely useful for improving both the mechanics and content of the module itself.

Furthermore, we will provide a venue for faculty to provide feedback about how they felt the modules helped them to achieve their implementation plan. Interviews with the faculty and pre- and post-analysis of their quantitative content will help us to improve the effectiveness of each module. In this way, each module becomes a collection of the best teaching ideas about the quantitative topic by those who use it. This improvement may come in the form of new topics in the sample or quiz problems, a more effective algorithm for a given topic, clearer instructions, or any number of small improvements.

Evaluation: Evaluation of the success (and future modification) of the project will be based on qualitative and quantitative data collected from faculty and students involved in the implementation, through an initial faculty survey about the nature of the implementation and follow-up interview conducted at the annual workshop or via telephone, as well as through student pre-and post-testing and end-of-module questions identified as useful in the pilot project. Data collected will include:

- Dissemination of the implementation model, including innovations, modifications, course and institution descriptions, in the form of a public webpage.
- Faculty perception of ease of use, increase in quantitative content of the course, student achievement
- Student perception of helpfulness and difficulty (both in terms of the modules and the course itself)
- Student improvement from pre- to post-test
- Faculty qualitative evaluation of what worked (and what did not)
- Faculty assessment of how they might change the implementation to improve it.

BROAD DESIGN OF ACTIVITIES

This project will take 4 years to complete. The first year involves training and coordination of 5-8 first-round implementers and the coordination of these implementations. Working closely with implementers, Wenner and Baer will review syllabi, and class content to identify and generate an implementation model that will be effective in a given class. Following these meetings, Baer and Wenner will begin to write and adapt modules to support implementation in the first-round of courses. Experience with coordination, evaluation and module writing at their own institutions suggests that each of the PIs will need two months FTE for coordination and evaluation and a summer month for workshop planning and realization.

In the second and third years, the PIs will coordinate the implementation of TMYN at twice as many schools. However, we anticipate approximately the same amount of time will be spent because we will have more complete modules and a better handle on the types of hurdles that implementers will need to get over. Each of these two years will also involve a two-pronged workshop, beginning with summary activities with previous-year implementers and culminating with the new cohort designing their implementation plan for the following years. We also anticipate that new or improved modules will be in place, new questions will be designed for the quizzes and we will have several successful models for the new cohorts to draw from in each successive year.

By the fourth year, we anticipate spending time coordinating the final cohort (trained in the third summer) and designing an appropriate self-sustaining online workshop. In addition, we will focus on analyzing the data from all ~50 institutions and instructors who use TMYN, as well as continuing the support of the use of all the modules. We anticipate that at this time the use of the modules will be mostly self-sustaining so that the PIs can focus of analyzing results to provide data-supported best practice guidelines for using these and other web-based student support.

MEASURABLE OUTCOMES AND BROADER IMPACTS OF PROPOSED WORK

At the culmination of the expansion of TMYN project, we will have several measurable outcomes:

- Generate up to 40 implementation models for the use of The Math You Need, When You Need It in conjunction with introductory geoscience courses. Each model will be presented to the broader geoscience community through a webpage hosted by SERC that outlines the nature and objectives of each implementation, successes, failures, lessons learned, and modifications made through continued use.
- Production and use of 6-10 new modules that will be tested by our institutions and others who use the modules, for a total of 14-18 modules for the entire project.
- A large dataset of information about student performance and learning of quantitative skills in introductory geoscience courses, student and faculty perception of the use of TMYN, and faculty input about their implementation successes and modifications.
- A network of geoscience faculty members who include quantitative topics in their geoscience courses. These faculty will be leaders in the field and will be helpful in increasing the number of faculty effectively using the program.

The proposed work is designed to have broad impacts on the educated citizenry of the United States by increasing the quantitative literacy of students enrolled in general education science courses. First and foremost, this project will have a positive impact on student persistence and retention in introductory geoscience courses by providing them with online support for the mathematics they need to succeed in these courses. Secondly, the proposed expansion will impact student literacy by increasing the number of geoscience courses that actively engage students in quantitative concepts in real-world contexts. . Quantitative literacy is vital to the goals of a broad, liberal arts collegiate education; yet current introductory geoscience courses miss important opportunities to bolster students' quantitative literacy. Students who are exposed to quantitative topics will develop scientific and critical thinking skills that are essential to being a productive citizen in this number-filled society (e.g., Steen, 2001).

Finally, the results of this project have implications for STEM fields beyond introductory geoscience courses, as success in a variety of general education sciences courses (e.g., environmental science) hinges on students being able to reason quantitatively in specific scientific contexts. More specifically, we believe that TMYN provides an effective model for a variety of STEM courses wishing to remediate students' in mathematics using out-of-class, online resources. As such, the results of this project will be interesting to faculty outside of geoscience and hold the promise of having an impact on the larger STEM community.

USING CURRENTLY AVAILABLE RESOURCES

Web infrastructure supported by SERC

Carleton College's Science Education Resource Center (SERC) already hosts the existing 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%

TMYN website is constructed using SERC's content management system (CMS; Fox et al., 2005), which supports the rapid development of content-driven web pages and searchable collections. 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 10,000 pages of original content written by hundreds of authors. Indeed, the 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.

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 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.

Widespread dissemination via the Internet and print publications

Because SERC's website receives over 11,000 visitors a day (Manduca, pers. comm., 2006), publication on the site assures rapid and widespread dissemination of materials we create. Website usage statistics illustrate the significant number of geoscientists who will potentially be reached through this important venue: During November and December 2008, our existing modules were viewed by more than 8000 visitors, and approximately 1000 unique visitors per month appear to spend time using the pages (based on number of minutes and page views within TMYN). Modern students and faculty find that the universal access and ease of use of websites provides 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.

We will also disseminate results through traditional means such as presenting at professional meetings, and publishing results in widely read journals such as *Numeracy* and *Journal of Geoscience Education* (JGE). Both PI's have successful publication records in these journals. Dissemination at a wide variety of professional meetings (such as AGU, GSA, and more regional meetings) is particularly critical, as it is a means for recruiting new users and to discuss implementation in a more informal and personal manner. The National Association of Geoscience Teachers also officially sponsors the Math You Need; newsletters, flyers and other NAGT publications will also provide a means of disseminating this information

COMMUNITY BUILDING

This project will create a community of educators who are teaching introductory geosciences classes quantitatively. We have carefully designed the faculty development workshops to further this goal. By bringing faculty together at workshops before they begin the project, we will create the connections, interactions and bonds that lead to effective collaboration both within this project and beyond. We further support that collaboration by having the same cohort meet one year later to report their results, further strengthening these bonds. Finally, we will train new leaders in the use of TMYN by asking the previous year's implementers to train and mentor the next cohort of faculty, creating a self-sustaining model for use and a supportive community of educators. The community built by this project can be said to be held together with several common threads – all participate in the project, teach introductory geoscience classes, and have interests and desires to teach geoscience quantitatively. Nonetheless, community members are drawn from a variety of institutions and programs, spanning institution types that may not typically interact with each other. In this way, the TMYN implementation community will provide participants with a unique ability to make connections and develop previously unforeseen collaborations.