An assessment of STEM faculty involvement in reform of introductory college courses

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Abstract:

Twin strategies of Institutes on the Teaching and Learning of Science and Mathematics and support for faculty through mini-grants are shown to be effective in stimulating college science and mathematics faculty to modify their introductory courses to include more active learning strategies. The institutes were designed to provide faculty who are normally not familiar with the literature with an opportunity to learn about how students learn. Mini-grants provide faculty with incentives to become involved. The strategies are sustainable and spread beyond those faculty initially involved in the initiative.

Introduction:

Introductory college courses in science, mathematics, engineering, and technology (STEM) fields have a strong influence on the number of students who successfully graduate as STEM majors or who become science and mathematics teachers. Tobias (1990) found that 40% of students who considered being a STEM major abandoned their interest after their first undergraduate STEM course. Similarly, Seymour and Hewitt (2000) found that approximately 40 percent of undergraduate students leave engineering, 50 percent leave the physical and biological sciences, and 60 percent leave mathematics. To address this attrition issue, educational innovators in the various STEM disciplines have been guided by research findings that are summarized in Bransford, Brown, and Cocking (1999) and Kilpatrick, Swafford, and Findell (2001). Students can learn more science and mathematics in classes where they interact with faculty, collaborate with peers on interesting tasks, and are actively engaged with the material they are learning. However, as noted by Fox and Hackerman (2003), most faculty are not aware of the literature.

Successful course innovations that increase student learning in large enrollment introductory courses have been employed by a few faculty. For example, in physics, Hake (1998), McDermott and Redish (1999), Fagen, Crouch, and Mazur (2002) and Pollock and

Finkelstein (2008) have introduced techniques for actively engaging students in their learning that have positive benefits. Pollock and Finkelstein discuss how to sustain educational reforms in introductory physics.

This paper discusses some strategies that have proven to be effective in stimulating a large number of STEM college faculty in multiple institutions to modify their introductory courses to include more active learning strategies in introductory science and mathematics courses that subsequently increased success rates for students. The evaluation is a mixed-method design that includes both quantitative and qualitative assessments. Johnson and Onwuegbuzie (2004) cite several strengths of using such a mixed-method design.

Context:

In October 2003, NSF funded the Partnership for Reform In Science and Mathematics (PRISM), an initiative of the Board of Regents of the University System of Georgia (USG) in partnership with the Georgia Department of Education and four regions that include six USG colleges and universities and 15 school districts. http://www.usg.edu/p16/initiatives/prism.phtml. The six USG institutions included two two-year colleges, two state universities, and two research universities.

An overarching question posed by the NSF Mathematics and Science Partnerships (MSP) initiative http://www.nsf.gov/ehr/MSP/nsf05069_3.jsp is: "Does sustained involvement of higher education science and mathematics faculty contribute to further understanding about teaching and learning science and mathematics and, with their participation in the implementation, lead to improved K-16 student achievement in science and mathematics?" This paper will examine the part of the question related to involvement of STEM faculty and their impact on introductory college courses.

One of the first issues faced by PRISM was how to involve science and mathematics faculty in its activities. Two interrelated strategies utilized by PRISM were an Institute on the Teaching and Learning of Science and Mathematics (Institute) and a Mini-grants program.

Strategies:

The assumption underlying the work is that many science and mathematics faculty are not aware of how students learn. They are not familiar with advances in learning theory and cognitive sciences as summarized in Bransford et al. (1999) and Kilpatrick et al. (2001). As noted by Fox and Hackerman (2003), not only are faculty not familiar with the literature, they do not have time, opportunity, or incentives to learn from it. The question posed is: "By providing faculty with an opportunity to learn similar lessons to the findings in the literature, will faculty modify their courses and will more students be successful in introductory college science and mathematics courses?"

A combination of statewide and regional strategies was designed for higher education faculty from science, mathematics, science education, and mathematics education. These faculty were engaged through an Institute and a Mini-grants program.

Institute:

The Institute is designed to provide faculty a Learning Community in which to examine their own classroom practice, and to learn about, experiment with, and share various effective teaching approaches in science and mathematics that actively engage the learner, in ways on which others can build. Initially, the statewide Institute sponsored two two-day workshops per year. Participants in the Institute included higher education faculty and high school science and mathematics teachers, chosen by the regional directors. The statewide Institute paid for participant travel costs and the institutes were held on Friday-Saturdays. Attendance was limited to 80 participants at each statewide Institute, with 20 participants from each region. The meetings featured plenary speakers who are credible national practitioners who engaged participants actively in the sessions. There was structured time for both regional, cross-discipline sharing and for cross-regional within discipline sharing.

Each of the four regions had regional institutes to stimulate ongoing initiatives and discussions in the time intervals between statewide workshops. Regional institutes provided the ongoing stimulus to faculty from the PRISM participating institutions and eventually incorporated an annual one- or two-day workshop in addition to regular meetings. Faculty who attended the statewide meetings shared ideas with their colleagues at meetings of the regional institutes. There were many more faculty members involved in the regional institutes than were invited to the statewide meetings. Regular regional institute meetings provided on-going follow-up support. In particular, regional institutes have provided arenas for faculty to learn about 'action research' or 'classroom research' and institutional research boards (IRB), issues with which science and mathematics faculty are not normally familiar. All faculty involved with regional institutes were eligible to compete for mini-grants, with about half of them receiving funded support.

External experts were primarily the plenary speakers for the statewide institutes. For example, for the first institute that was held in April 2004, there were presentations by Rich Lehrer (Vanderbilt) from the '*Knowing what Students Know'* National Research Council (NRC) committee (Pellegrino, Chudowsky, and Glaser 2001) and Jose Mestre (then at U Mass Amherst) from the '*How People Learn'* NRC committee (Bransford el al. 1999). In addition, there were sessions on problem-based learning and collaborative and cooperative learning in higher education. The original focus of the institutes was to provide STEM faculty with an opportunity to learn how students learn in the various disciplines.

From this basic introduction to research findings that suggest that students at all levels build new knowledge and understanding on what they already know and believe, the second meeting in October 2004 was organized around common student misconceptions - how to identify them and strategies for addressing them in the classroom. In addition to plenary speakers, there were breakout workshops for biology, chemistry/physics, and mathematics led by Gordon Uno (U. Oklahoma), Jose Mestre, and Brad Findell (then at U. Georgia), respectively.

While students are known to have misconceptions, a question is how to assess and address these misconceptions, especially in large classes. The third meeting was held in February 2005 and its focus was on student assessment and use of scientific teaching through activities in large sections of introductory classes. Diane Ebert-May (Michigan State University) and Pamela Kraus (FACET Innovations) engaged the participants in hands-on activities in biology and physics, respectively, and on the use of elicitation questions. The plenary talks were supplemented with two concurrent sessions where faculty from the four regions presented some of their assessment initiatives.

The fourth statewide institute meeting in October 2005 featured more workshops on formative assessment and disciplinary assessment tools with assessments in mathematics featured in a plenary by William Martin (North Dakota State University). Subsequent statewide institute meetings featured such topics as "Generating Inquiry Questions in Science and Mathematics" and "Importance of Inquiry: Scientific Teaching in Science and Mathematics".

After the February 2005 statewide meeting, the regional institutes started to hold annual retreats as well as regular meetings, with the first one being a two-day retreat held by the NE

Region in April 2005. With the rise in regional institute retreats that were held each spring, the statewide meeting moved to an annual fall meeting. To a limited extent, USG faculty were presenters or facilitators initially in the statewide institutes but more so later on, especially in the regional institutes. In addition to involvement in regional institute meetings, some of the departments have called on participating faculty from the statewide institutes to present at their department meetings and retreats.

Mini-grants:

Mini-grants have been used to provide the impetus that busy faculty need to work on issues related to implementing new teaching strategies and improving student learning. A regional mini-grant program invited proposals from faculty to experiment with strategies of student engagement and assessment of student learning and share knowledge of evidence-based research on the teaching and student learning of science and mathematics, especially in introductory classes.

The Northeast (NE) Georgia region initiated a mini-grants program in summer 2004 to provide funding to college faculty for innovative projects related to improving instruction and student learning in science and mathematics at the undergraduate level at the University of Georgia (UGA) and Georgia Perimeter College. Other regions followed the NE Georgia region's lead and developed their own mini-grant programs. Mini-grants were also used as a strategy to involve higher education faculty in K-12 schools. The other three regions extended the scope of the proposals to include improving instruction and student learning in K-12 schools. In all four regions, there had to be at least one higher education faculty member associated with a mini-grant project.

While the 2004 and 2005 year call for proposals by the NE Georgia region included any undergraduate science and mathematics course, the 2006 year RFP narrowed the types of courses to those in which pre-service teachers might typically enroll. Examples of proposals that might be supported included analysis and improvement of courses, creation of new course modules, materials or assessment tools to enhance courses, or research on the effectiveness of an already implemented innovation. Twenty proposals were funded in the initial round of which eight were focused on introductory courses. In the second round, eighteen proposals were funded with six on introductory courses. In the third year, ten grants were awarded of which eight were focused on introductory courses. Goals for the third-year RFP were narrower and more clearly stated. As a consequence, proposals were focused on development and implementation of instructional and/or assessment strategies that engage students in inquiry-based or problem-solving activities to improve student learning. Thus, in the NE Georgia region, the RFP process evolved to a more focused call by the third year.

In the Metro Atlanta (MA) Georgia region, six of twelve proposals in 2005 were focused on introductory courses and another four in the second year. In the East Central (EC) Georgia region, only one of the funded proposals focused on introductory courses and there were none in the South East Georgia region. These three regions placed more focus on stimulating faculty to work with K-12 schools and on enhancing current teachers' knowledge and comprehension of science and mathematics content and inquiry-based and interactive teaching methods. Only proposals related to improvement of introductory college courses are discussed below. Table 1 summarizes 32 proposals on improvement of introductory courses that were funded for 2004-2007 in the four regions.

In addition, all funded mini-grant projects were required to use a modified structured abstract format (Mosteller, Nave, and Miech, 2004) for their reports. This aided significantly in promulgation of results from the projects through presentations and publications.

<u>Data and Analysis:</u>

Triangulating data from various sources is always necessary to enhance the trustworthiness of a study. In this paper, two sets of qualitative data and two types of quantitative data are analyzed. Qualitative data on changes in instructional pedagogy in introductory science and mathematics courses were studied through a survey of institute participants and a survey of some mini-grant recipients. One set of quantitative data is the number of refereed journal articles submitted or published was measured. In their publications, faculty members describe modifications to their courses and increases in success rates and/or increases in scientific literacy, etc. Only samples of findings of quantitative data on improvement on student success rates in courses are described in this paper.

Data were collected from participant surveys following the statewide Institutes. The survey instrument used for the Institute included a 6-point Likert rating of the speaker/sessions and their usefulness to the participant plus a number of open-ended questions. For the first Institute, the questions included:

- How could the conference have been made more useful?
- Describe one good idea that you plan to implement when you return to your institution.
- What topics would you suggest for future workshops?

By the second statewide institute, regional institutes had been created. For the second and third institutes, the open-ended questions included:

- Did you learn about student assessment strategies that you will try in the courses that you teach? If yes, please identify strategies you plan to use and where you will use them in.
- What difficulties do you anticipate encountering when you implement some of the assessment strategies you learned about during the Institute?
- How effective do you believe the Institute is in improving the teaching and learning of college professors in science and mathematics in your region? Please explain.
- Please describe how the state PRISM Institute informs your regional institute and how they are related.

For the fourth institute, the open-ended questions asked about inquiry strategies instead of assessment strategies. Since this institute included sessions where some mini-grant recipients gave presentations, an additional question was:

- Did you learn any strategies in the mini-grant sessions that you will try in the courses that you teach?

Participants have rated each of the statewide institutes highly. Meetings have been successful because they feature plenary speakers who are credible national practitioners who have engaged participants actively in the sessions. Speakers modeled behavior in their sessions that was being promoted for large-sized classes. For example, for the Institute held in November 2006, there was a mean of 4.78 with 93% of the respondents rating the institute as useful (rating of 4 or above on a six-point scale). In the evaluation survey of participants at the February 2005 Institute, 85% (34 of 40) respondents stated that they learned about student assessment strategies that they will try in the courses that they teach. Similar positive data were obtained following each of the statewide Institutes meetings. The PRISM evaluation team analyzed data after each of the statewide meetings and provided feedback for improvement of subsequent meetings. Participant comments included: “Great opportunity to learn from experts” and “Showed concrete examples of how to augment my student’s learning with more hands on learning”. Topics of interest that many faculty appreciated learning about included elicitation questions, concept maps, and use of rubrics.

In June 2007, the NE Georgia region conducted a survey of 33 mini-grant recipients that included only arts and science or agricultural undergraduate course interventions and assessments to which 14 faculty responded (N. Vandergrift, private communication, 2007). All 13 successful course interventions have been continued in subsequent offerings of the course; 7 reported that course interventions have transferred to other courses taught by the same faculty; and 9 indicated that course interventions have been sustained and/or expanded to other sections of the same course - taught by different faculty. In addition, 4 faculty indicated they had been recognized by the university for their contributions in course improvement [beyond annual review or merit salary increases]. Also, 5 of the faculty have submitted at least one manuscript to a peer-reviewed journal[i]. Further, 12 other faculty who were part of other regions and/or were not surveyed have submitted at least one manuscript to a peer-reviewed journal[ii]. Of the 32 new awards in 2004-07 in Table 1, eight faculty (including 3 of those included in note[i]) have submitted ten manuscripts to peer-reviewed journals as of December 2008. All manuscripts are related to teaching and learning or the course innovations undertaken.

Examples of data collection of student grades include: In one set of biology courses that were redesigned to be theme-based (Trevistan and Poole, submitted), for fall 2005, students receiving a grade of D, F or W (DFW rate) in the redesigned course was less than half that of the traditional course, with a DFW rate of 12% in the redesigned sections and 30% in the traditional sections. Similar results are obtained in subsequent semesters.

For an intervention that modified introductory biology labs from cookbook to inquiry-based (Armstrong and Brickman, submitted), pre-post assessments were used. Assessments were used to evaluate student performance in the new inquiry and cookbook labs taken by over 1,200 students in more than 70 lab sections. One was a science literacy exam based on a similar test developed by Norris and Phillips (1994) that examines whether students understand how to read texts dealing with scientific subjects. A second test modified after one developed by Ebert-May et al. (1997) examines students' science proficiency at designing and interpreting scientific experiments and results. Authors' analysis of the data indicates that students in the inquiry-based labs showed statistically significantly greater improvement that than students in the cookbook labs on the science literacy test. On the science proficiency skills test, students in the inquiry-based labs also showed significantly greater improvement in their ability to design experiments and create/work with graphs than students in the cookbook labs but no difference was seen regarding quantitative skills or identification of dependent/independent variables.

Evidence is also obtained to support the claim of success rates for students in mathematics. Data were collected on student success rates in Mathematical Modeling, College Algebra and Pre-Calculus (Table 2). Student success rates for these courses have increased each year from 2003-06 within the six PRISM institutions. For the USG system as a whole, the increase has been smaller with a slight decrease seen in 2005 for College Algebra and Pre-calculus. The PRISM institutions have a slightly higher percentage of students passing with an A, B, or C than the USG system. While one competing theory of improved student success is that only increased student effort will lead to increased student learning, it is unlikely that students in the six PRISM institutions behaved differently on average than students in the other 28 institutions. A more likely explanation is that faculty interventions in the courses in the six institutions increased student success. It is noted that most of the course interventions were in mathematics modeling and college algebra.

<u>Conclusions</u>:

An assertion is that it is possible to use a combination of statewide institutes, regional institutes, and mini-grants to engage science and mathematics faculty in meaningful and potentially lasting changes in their introductory courses. Data that support this assertion are primarily in the published papers and in the survey results on mini-grants. There is descriptive evidence cited above from the NE Georgia region to support this claim. There are many more faculty involved in significant course modifications than had been the case before PRISM. There are similar results from the other three regions.

This set of strategies was initiated before the USG passed a “Work in the Schools” policy in October 2006 that encouraged potential changes in attitudes towards this type of work http://www.usg.edu/academics/handbook/section4/4.03.02.phtml . In addition, the number of faculty involved is expected to increase since USG is funding a STEM initiative that incorporates the combination of strategies described in this paper. Thus, there is significant potential for sustainability of improvements in introductory science and mathematics courses throughout the university system.

As noted by Fox and Hackerman (2003), not only are faculty not familiar with the literature, they do not have time, opportunity, or incentives to learn from it. The statewide and regional institutes provided faculty with an opportunity in which to learn from national peers and each other. Mini-grants provided support for faculty to adopt findings from the literature and what they learned at the institutes. Faculty were shown how to conduct classroom research and were allowed to personalize the findings in their own classrooms. Implications are that faculty need to be provided a structure and support if meaningful, sustainable modifications are to be implemented in introductory college courses and labs. However, it is also implicit that there has to be time to try out new things and there has to be value in the form of recognition and/or significant intrinsic satisfaction with improved student learning.

The twin strategies analyzed in this study might have limited generalizability since successful implementation frequently depends on local context. However, further validation could be obtained through follow-up studies by other institutions and/or higher education systems.

Pollock and Finkelstein (2008) explore important questions that are not part of this study. In particular, on the hand off from one faculty member to another, is the level of student achievement sustained at the level realized initially? To date, in the present study, faculty to whom the hand offs are made are 'informed' faculty in the language of Pollock and Finkelstein, i.e. they have participated at least in the regional institutes. Follow up work needs to be made at the course level to determine sustainability and spread of improvements in student learning.

Many of the course interventions are adding to the literature on the efficacy of active learning strategies in introductory courses. Fidelity of individual course interventions need to be scrutinized on a case-by-case basis that is most easily achieved through a rigorous peer reviewed publication procedure.

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Table 1 Mini-grant awards for modifications to introductory college science courses

Subject	Year*	# students	Title/theme
biology	'04	1,200	Conversion of non-majors introductory biology laboratories from a cookbook to an inquiry-based format
biology	'04	850	Introductory biology: Designing, implementing and testing an inquiry-based laboratory manual
biology	'04	350	Sea to See: Marine biology for the non-scientist laboratory curriculum development and outreach
biology	'04	750	Curriculum reform for an introductory biology sequence

chemistry	‘04 ‘05	350	Peer teaching in large freshman chemistry classes
chemistry	‘04	350	Misconception busters
geography	‘04	1,300	Active learning and peer teaching in intro physical geography
geography	‘04 ‘05	350	Development of a “Hands On” curriculum for an introduction to weather and climate lab
physics	‘04	80	Study of the effectiveness of using PRS to teach introductory physics
astronomy	‘05	450	Innovative astronomy teaching using lecture activities
biology	‘05 ‘06	130	Redesign of intro biology course into a more student-centered approach for non-majors biology
biology	‘05	400	Development of a computer-based notebook to enhance project-based learning in introductory biology labs
biology	‘05	180	From cookbook to inquiry-based labs in introductory organismal biology
chemistry	‘05 ‘06 ‘07	8,500	Analysis of computer based assessments and peer tutoring in a general chemistry program with a new development of chemistry elucidation questions
chemistry	‘05	200	Case Study – Titration of metal ions in salad dressings using EDTA – introductory chemistry labs
geology	‘05	600	Development of assessment tools for introductory physical geology and introductory historical geology courses
mathematics	‘05	1,000	Extending the MILE: Instructional professional development program
mathematics	‘05 ‘06 ‘07	1,000	The impact of redesigning college algebra and pre-calculus courses
astronomy	‘06	450	Development of observational activities for introductory astronomy labs
astronomy	‘06	110	Development of two astronomy lab courses that utilize collaborative learning techniques
biology	‘06 ‘07	80	Improving pre-service teachers' learning of biology: A case-based strategy for practical inquiry
biology	‘06	500	Using peer-evaluation and web-based software to enhance student writing and learning
biology	‘06 ‘07	500	Measuring scientific literacy as a function of inquiry in non-science major undergraduate labs
biology	‘06	380	Uncovering challenges and altering misconceptions about flow of matter in ecosystems
biology	‘06	130	Enhancing active learning in introductory level anatomy and physiology labs
biology	‘06	150	Enhancing active learning in two introductory level biology classes
chemistry	‘06 ‘07	100	Incorporation of online video supplemental material for chemistry lab

geography	‘06	350	Development of inquiry-based exercises on severe weather and hurricane forecasting for an introduction to weather and climate lab
geography	‘06	350	Enhancing climate change science education through inquiry-based concepts and real-world simulations
mathematics	‘06	400	Using interactive communication courseware to encourage active learning in hybrid pre-calculus courses
physics	‘06 ‘07	130	Matter & Interactions: Testing a new physics curriculum
mathematics	‘07	700	Project characteristics that affect student comprehension in elementary statistics

*When more than one year is listed, the study received additional funding for the subsequent years

Table 2. Pass rates for mathematical modeling, college algebra, and pre-calculus – Comparison of percent of students in PRISM partner institutions and all USG institutions passing the course with an A, B, or C grade.

Year	Course name	PRISM institutions	All USG institutions	Change in %
2003	Math modeling	61.4%	61.4%	0.0%
2004	Math modeling	64.1%	64.0%	0.1%
2005	Math modeling	66.5%	64.1%	1.4%
2006	Math modeling	67.8%	63.9%	3.9%
2003	College Algebra	56.1%	54.7%	1.4%
2004	College Algebra	56.8%	55.7%	1.1%
2005	College Algebra	55.9%	54.5%	1.4%
2006	College Algebra	58.7%	55.9%	2.8%
2003	Pre-Calculus	58.7%	56.8%	1.9%
2004	Pre-Calculus	59.2%	58.3%	0.9%
2005	Pre-Calculus	60.2%	58.1%	2.1%
2006	Pre-Calculus	61.9%	59.9%	2.0%

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