Enhancing Inquiry-Based Science and Math in Appalachian Middle Schools: A Model for Community Engagement

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ABSTRACT

Faculty at public comprehensive universities are required to engage in professionally related service to their communities. In contrast to the traditional one-way interaction with university personnel as the service providers, institutions of higher learning can engage in service activities that are mutually beneficial to the community and the university. This paper describes a partnership between a comprehensive university and six middle schools from the rural Appalachian region of Kentucky that can serve as a model for community engagement. The project was designed to enhance middle school student learning in the areas of science and mathematics. Its objectives were accomplished through a three-person team structure requiring the active participation of a middle school teacher, a university science or math professor and a college student. The K-12 teacher provided expertise on pedagogical and curriculum issues, the professor provided support on content and applications, whereas the student played the leading role in the development and application of instructional activities. The middle schools benefited from enhanced student learning, content applications of science, mathematics and technology, and use of inquiry-based pedagogy. The university benefited from professional development opportunities to faculty in the areas of service, scholarship and teaching. There were also several benefits to the participating university students including improved communication, teaching, and team building skills, increased knowledge about both the content and applications of science, mathematics and technology, and support for graduate education through generous stipends.

Keywords: inquiry-based instruction, community engagement, middle school science/math

Introduction

Faculty at public comprehensive universities are required to engage in professionally-related service to the community by drawing on their professional expertise to serve such entities as community groups, business, educational institutions and government. Traditionally, community service activities have tended to be one-way (outreach) with university personnel providing services to entities outside the university. However, it is now realized that universities can engage in service activities in a manner that benefits both parties. This has given rise to the term community or public engagement. The Carnegie Foundation for the Advancement of Teaching defines community engagement as “the collaboration between institutions of higher education and their larger communities (local, regional/state, national, global) for the mutually beneficial exchange of knowledge and resources in a context of partnership and reciprocity” (Driscoll, 2008). The engagement can involve teaching, scholarship, and/or service. In addition to being mutually beneficial, an activity must relate to the faculty member’s discipline or role at the university, and must serve a group other than the faculty member’s own disciplinary or professional association to be considered “engaged service.”

The new way of viewing community service is a result of efforts to enlarge the definition of research (scholarship) in order to realign the priorities of faculty with the essential missions of American colleges and universities (Barker, 2004; Boyer, 1990; Glassick, Huber, & Maeroff, 1997; O’Meara & Rice, 2005). While faculty are engaged in a full range of academic functions classified broadly in the areas of teaching, research and service, the reward system (reappointment, tenure, promotion, merit pay, etc) is heavily influenced by research productivity. The concern has been that faculty may pay less attention to undergraduate education, a primary focus of many comprehensive universities. Furthermore, research has been traditionally defined in a narrow sense raising concerns that professors may not adequately engage in critical societal issues if they pursue narrowly specialized research agendas.

K-12 schools are logical entities for universities to be engaged with in service since both types of institutions are part of the education enterprise. Throughout the United States of America, K-12 school systems and teachers are experiencing the pressure of systematic education reform coupled with high stakes testing in response to national and state legislation. One rationale for these changes is the less than favorable comparisons of U.S. students on international tests. In particular, our middle school students often do not compete well in the areas of math and science (National Center for Education Statistics, n.d.). Many middle school teachers feel like they are caught in the middle of this problem. Their dilemma is this, "How do I teach math and science well while providing students with the content background that will enable them to compete in this testing environment?" In order to help teachers grapple with this challenge, conversations among university administrators and professors and middle school principals and teachers informed the writing and submission of a grant proposal to the National Science Foundation's (NSF) Graduate Teaching Fellows in K-12 (GK-12) program (American Association for the Advancement of Science [AAAS], 2010). The resultant award led to the implementation of a project called Inquiry-Based Science and Math in Appalachian Middle Schools (ISMAM) from 2003 to 2006 as a partnership between Eastern Kentucky University (EKU) and six middle schools in EKU's service region. The ISMAM project was the first GK-12 program in Kentucky.

The ISMAM project, including the lessons learned from it, is herein described so that it may serve as a model for partnerships between universities and K-12 schools. Although there are other similar projects that have been funded by NSF (AAAS, 2010), each has its own uniqueness based on local factors and the implementation strategies of project leaders. For instance, the three-person implementation team structure in which a university science or math professor is actively involved is a unique aspect of ISMAM.

Research on Inquiry

ISMAM was based on research showing that inquiry teaching results in meaningful learning in the areas of math and science. Inquiry-based instruction is advocated as an essential strategy for teaching science by the National Science Education Standards (NSES). Inquiry is defined by NSES as a "multifaceted activity that includes making observations, posing questions, examining evidence, planning investigations, analyzing and interpreting data and proposing answers. It requires the use of critical and logical thinking." This occurs "when students are frequently engaged in active inquiries" (National Research Council, 1996, p. 145). Research supports the effectiveness of inquiry based teaching strategies in increasing students' scientific understanding of a variety of concepts. For example, Trundle, Atwood, Christopher and Sackes (2010) found that students' understandings of lunar phases and their causes were more scientific after engaging in guided inquiry instruction. In another study Lee, Linn, Varma and Liu

(2010) found that students' ability to integrate knowledge of complex science topics increased after learning through online, visualization rich inquiry units. A district wide project in Detroit (Geier, Blumenfed, Marx, Krajcik, Fishman, Soloway, & Clay-Chambers, 2008) found that seventh and eighth grade students involved in project based inquiry science scored significantly higher on statewide achievement tests and that these achievement gains persisted over a year and half.

National Council of Teachers of Mathematics (NCTM) also advocates the use of inquiry through their standards, which emphasize the use of problem solving, reasoning and real world applications (NCTM, 2000). Research showing the effectiveness of these strategies has been conducted by Schoen, Fey, Hirsch and Crawford (1999). They have found that middle school students who learn through guided inquiry with real life applications develop better reasoning abilities and are able to make connections between abstract math concepts and authentic applications. Other researchers have shown that this type of instruction permits students to make interdisciplinary connections (Drier, Dawson, & Garofalo, 1999). Because of the many studies showing the benefits of inquiry-based instruction, this pedagogical approach is taking root in many K-12 classrooms across the country (Beamon, 2002).

Middle School Students and Inquiry

Another facet that made this project successful is the fact that inquiry and middle school students are a natural combination. The practice of active inquiry-based science and math instruction meets the cognitive, psychosocial and physical needs of this age group (Jorgenson, Cleveland, & Vanosdall, 2004). Cognitively, middle school students are curious and interested in learning but are operating at various cognitive levels. Inquiry allows students to investigate interesting questions and process information at a variety of levels. For example, one student may be involved in the concrete task of collecting data while another performs the higher-level skill of analyzing the group's results. In order to be motivated to learn mathematics and science, middle school students need to see the relevance to their lives of what they are learning and this can be structured through these investigations.

The psychosocial needs of these students are also directly targeted through inquiry learning. Although students at this age seek independence, the changes that they are going through require structure to provide a predictable, safe environment for learning. Guided inquiry (Exploratorium, n.d.) in which the teacher designs the problem and procedures but not the conclusions of an investigation helps to meet middle school students' need for structure. The degree of organization can fluctuate by changing the amount of teacher guidance in the inquiry activity. The activity centered approach to science and math addresses the students' tendencies to become easily distracted or bored. The social needs of these students are met through collaboration. Collaboration and inquiry are natural partners with group investigations allowing middle school students to socialize in an appropriate manner.

Physically, middle school students need to move on a regular basis. The active nature of inquiry gives them an appropriate venue to get up and move around the room. A variety of math and science manipulative skills such as using scientific equipment are taught and refined through this type of teaching. Consequently, good science and math instruction utilizing collaborative, active inquiry investigations is also consistent with addressing the changing physical needs of a middle school student.

Objectives, Organization and Training

The primary goal of ISMAM was to promote interest, achievement, and excitement of inquiry in science, technology, engineering and mathematics (STEM) among middle school students. This goal was pursued through five specific objectives, namely:

1. To increase middle school student interest, learning, and achievement in STEM subjects.
2. To improve and update the middle school teachers' content knowledge in STEM disciplines, and its applications, and increase their confidence level in applying this knowledge.
3. To promote partnerships between the University and local middle schools.
4. To improve the communication and teaching skills of Fellows (graduate or advanced undergraduate student).
5. To disseminate the results of the project's activities.

ISMAM's objectives were accomplished through a team structure. A team consisted of a middle school teacher, a university professor and a graduate or advanced undergraduate student (called Fellow). The role of the K-12 teacher was to provide expertise on pedagogical and curriculum issues, the professor provided support on content and applications, whereas the student played the leading role in the development and application of instructional activities. Six middle schools from the rural Appalachian region of Kentucky were involved in the project and there were two teams in each school. The schools selected to participate had relatively high proportions of low-income student populations, with 36 to 100% of the students qualifying for free or reduced lunch (Kentucky Department of Education, 2009).

The overall responsibility for the administration of the project rested with the project director. He was assisted by the coordinator who managed the school activities. With the exception of the coordinator who was from the College of Education, all the other participants were from a science or mathematics discipline within the College of Arts & Sciences.

Training was a crucial component of the project and was achieved in three different ways. First, all team members participated in an intensive, one-week summer workshop which was used to orient the Fellows and faculty to the realities of middle school teaching—developmental levels, classroom management, confidentiality, standards based instruction, and testing requirements. Participants also learned about inquiry-based instruction and how to implement it in a classroom. Additional training sessions were held as necessary throughout the implementation period and were conducted by local, state and national experts in the areas of identified need. Participants also met periodically throughout the duration of the project, either as individual teams or with the project coordinator for planning, brainstorming and sharing experiences.

Educational Activities for Middle School Students

Project teams developed new inquiry-based activities, adopted others, and modified some existing non inquiry-based activities to make them more inquiry in nature. The primary focus in the first academic year was on enhancing inquiry-based instruction at the middle schools. This focus was expanded in the second year to include increased use of technology, and in the third year to include the 5 E Learning Cycle model. Technologies identified as appropriate for middle school classrooms and consistent with the project's implementation strategies included Calculator Based Laboratories (CBLs), Lego Robots, computer based digital microscopes, and interactive mathematics and science software. The lessons and units developed by the teams were all designed to meet state and national content standards. Each team was provided with funds to buy equipment and expendables to carry out their activities. This was a significant contribution of the project considering that many middle schools have limited budgets for science and math equipment and supplies.

The Fellows spent an average of five hours a week preparing for project activities and ten hours a week working in the middle schools. They were responsible for designing, implementing and assessing inquiry instructional activities, including working with individual or small groups of students, planning inquiry-based lessons and units, teaching these lessons, facilitating discussions, and helping with routine classroom chores, thereby freeing the teacher to concentrate on student inquiry.

While the main focus was on inquiry-based activities, some "fun" activities, whose purpose was to get students excited about science and math were included. Examples of fun activities are the liquid nitrogen demonstrations and the use of K'nex challenges. By seeing liquid nitrogen freeze a variety of everyday objects and used to make ice cream, middle school students are definitely excited and motivated to become more engaged in science lessons. Through the K'nex challenges, students design and build a structure that meet certain specifications. For example, with the simple machines kit, students experiment with machine models that emphasize mechanical principles while demonstrating real world applications.

Fellows also planned, coordinated and/or participated in field trips, which enabled middle school students to observe real-world applications of STEM. Other trips exposed them to some of Kentucky's natural resources, gave them opportunities to conduct water quality testing activities and enhanced their awareness of environmental issues.

Project Evaluation

Evaluation was integrated into the ISMAM project in order to assess its impact. The project had an internal and an external evaluator. The evaluations focused on, first, providing information to the project staff during the course of the project on what was working well and what could be adjusted, and second, collecting data related to the expected outcomes of the project. The evaluations reported below are focused on more summative evaluations over the life of the project and are based on a wide range of data sources including:

1. Interviews with the Principal Investigator and Co- Principal Investigator
2. Observation of Fellows with teachers and middle school students
3. Conversations with EKU faculty.
4. Electronic and written surveys of Fellows, teachers and faculty
5. Annual administration of Science Attitudes Survey to middle grades students
6. Kentucky Department of Education annual test score data
7. Focus groups with teachers, Fellows and faculty
8. Participant observation in summer training programs
9. Review of data collected by Principal Investigator.
10. Ongoing electronic communications from project staff to participants

including e-mail communication with principals of middle schools.

11. Logs of meetings and reports of individual participants to Co- Principal Investigator, and reports of faculty visits to Fellows' schools/classrooms.

Evidence documenting progress on the first objective, to increase middle school student interest, learning, and achievement in STEM subjects is mainly anecdotal for a variety of reasons. State accountability tests are not administered in every subject every year. The ISMAM Fellows had different patterns of participation in classes. For instance, some met with one class over the course of the year, while others changed every nine weeks. Some taught entire lessons that they developed and observed or "helped" other times, while some helped teach every time they were in the school. Several schools were involved in more than one program related to this outcome. In addition, the state testing data are reported by school, not by classroom or teacher, and it was not possible to obtain individual student or meaningfully aggregated data.

Nevertheless, the anecdotal data suggest that change occurred. The comments of teachers in surveys and focus groups fell into four major areas with regard to student learning. The teachers reported that their students looked forward to having the EKU Fellow in their classes and that: (1) Students who were at the lower end of the academic spectrum were much more able to understand concepts and make connections using inquiry-based approaches. (2) The Fellows' presence seemed to involve the girls in math and science to a greater extent than usual. (3) Students asked more questions and answered more of their own questions. (4) Students seemed more confident in their knowledge of some concepts. Of the 12 or so teachers who responded to related questions on a survey, only one indicated that he saw no difference in student learning.

The Science Attitudes Survey, selected from a list of instruments provided by NSF, was administered each spring to all students in the middle schools. As its name implies, it is not a test of knowledge or skill. However, it is usually assumed that learning is related to interest and motivation. The data did not a direct causal link, when the Science Attitudes Survey was administered to all students in the middle school. However, students whose math or science classroom had an ISMAM Fellow showed consistently higher levels of interest in science, both now and in their future plans, than peers who did not have a Fellow in their classroom.

The second objective, to improve and update the middle school teachers' content knowledge in STEM disciplines, and its applications, and increase their confidence level in applying this knowledge, was successfully addressed according to teachers' comments in focus groups, training sessions, survey responses, and periodic reports. They cited in particular the use of computer-based labs, Lego robots, and inquiry-based teaching as providing skills and techniques they would continue to use in their teaching. In addition, content knowledge was updated in particular ways depending on the Fellow and the teacher. For instance, one Fellow did an extensive unit on botany of native plants, which expanded the content knowledge of the biology teacher she worked with. Another science teacher said:

My ability to work with computer programming languages (Lego robots) has improved dramatically. My understanding of digital circuits is very good as well. These areas, and the content that goes along with them, are ones that I had little understanding of before getting help from *my Fellow. Now I feel comfortable enough with them that I feel confident that I can do them on my own next school year.*

Several types of evidence document that the third objective, to improve the communication and teaching-related skills of the STEM Fellows, was achieved. The EKU faculty reported really strong gains in the Fellows' communication skills as evidenced by written work, individual conversations, and presentations within classes. The middle school teachers also noted changes in Fellows' communication skills both with the teachers and in interactions with middle school students. The strongest evidence came from comments of the Fellows in focus groups and in surveys, where several of them referred to their improved communication skills as one of the most important outcomes of their participation. Specifically, they mentioned that having to present concepts to middle school students had required them to think differently and develop the ability to communicate more clearly about content; they indicated that this approach would help them in learning and communicating more effectively in their future professions. Their presentations at professional meetings, in both formal sessions and poster sessions, and their writing for publication in journals were also cited. Several indicated that learning to write a clear abstract of an article was an important and useful skill.

The evaluators concluded that there was some evidence that the fourth objective, to improve the cooperation between public schools and the University, was achieved. In response to a survey administered to 12 middle school teachers, 6 said that the project had strengthened the partnership between their school and EKU significantly, 3 somewhat, 1 not significantly, and 2 not sure. In focus groups and in written comments, the teachers' responses also pointed to strengthened partnerships as illustrated by the following quotes:

Before this, I wouldn't have known who to contact or how to go about it. I wouldn't think I could just call the University and get any help, but now I know some people who know what I do, and I think I could call them and they would really try to help us with, at least with information or resources, like field trips. And my students really liked it when the professor came to our class. I think they know how welcome they would be.

and

Our principal is very supportive of the program, partly because she was a former science teacher…The teachers who have been involved have sung the praises of ISMAM. So I think the school has realized how beneficial it is. It's not just resources and equipment and things. It's the community that it's building – just by the faculty coming to our school. At first, I was kind of hesitant about how they change – each year you have anew faculty person, but now that I think about it, it just broadens the horizons…

The level of commitment on the part of EKU faculty was also mostly positive but by no means unanimous as illustrated by the following comments:

I will be much more willing to work with the public schools now than I was before, even if it's only judging science fairs. I actually had a good time in the middle school, and *now I know what challenges they're up against.*

and

I've started incorporating inquiry-type techniques into my teaching here, and I think I've learned some ways to help out in the middle school. It's not that hard, and I'll try to keep in touch. The biggest impediment is scheduling, when I don't always have control.

and

I doubt it (that I will continue working with middle schools). It's just too much!

The fifth objective, to disseminate the results of the project's activities, was achieved. Many participants took part in activities that informed others about the ISMAM project. Informal activities included parents' nights at the middle schools, presentations on campus, and a project newsletter. A website for the project provided a space where people could view the units and lesson plans developed by the Fellows and for photos of some of their projects. A workshop also was conducted for 29 middle school math teachers who had not been part of the project. Over 40 formal presentations were delivered at local, state, regional and national meetings from 2003 to 2006. In addition, three articles resulting from the project have been published (Godbey, Barnett, & Webster, 2005; McIntosh & Richter, 2007; Proppe & Harrel, 2007).

Benefits

Engaged service should be mutually beneficial to the community and the university. Increased knowledge about both the content and applications of science, mathematics and technology and increased expertise in using inquiry-based pedagogy on the part of middle school teachers and enhanced learning by middle school students were the major benefits to the middle schools.

There were multiple benefits to the university, particularly with respect to professional development opportunities for faculty. First, service was the primary focus of the project and, therefore, the project provided faculty the opportunity to contribute to the regional stewardship mission of the University. Second, the project provided faculty, and their students, with the opportunity to expand their scholarship beyond traditional disciplinary boundaries. As discussed previously, several publications and presentations resulted from project activities. Moreover, ISMAM-related activities formed the basis of honors theses projects of three students. These included investigation of misconceptions in kinematics and forces at Foley Middle School, investigation of the implementation and use of technology in the classroom at Clark Moores Middle School and a systematic study of the effectiveness of a standards based unit developed for force and motion at Madison Middle School. Finally, faculty learned much about inquiry-based learning and this has positively impacted the way they think about their college teaching. This is especially relevant to the Department of Physics and Astronomy at EKU that now uses the inquiry method in the teaching of all its introductory physics courses. There were also several benefits to the Fellows including improved communication, teaching, and team building skills, increased knowledge about both the content and, applications of science, mathematics and technology, and support for graduate education through generous stipends.

Lessons Learned

Some valuable lessons were learned from this project that should inform future endeavors on similar projects. First, this kind of project is complex and it takes time for individuals to appreciate their roles. Is the Fellow supposed to serve as a teacher's aid, a substitute teacher, or as a resource on disciplinary content and applications? Is the university professor supposed to develop lesson plans and units or should he/she just serve as a mentor and resource on content and applications for the team? Second, it takes time to develop partnerships where team members are comfortable with each other's roles. For example, Fellows need time to become comfortable with introducing new ideas in the middle school classroom without fearing that they will upset the teachers, and the teachers need time to get used to having somebody sharing instructional responsibilities in their classroom for an extended period of time. Working with six different schools was also a challenge since the schools had different needs and level of infrastructure. For instance, some schools had adequate computing facilities for the teams to introduce computer-based activities, while access to such facilities was very limited in others. Likewise, the academic preparations of the students varied from school to school. The project also involved Fellows and faculty from six different academic disciplines. This impacted flexibility in matching the Fellows to the needs in some schools. Probably the greatest challenge was implementing inquiry-based curriculum in the middle school classroom. Most middle school teachers are used to more structured lessons and experiments with predictable outcomes. In addition, they are always pressed for time to cover school or state mandated content so that students will do well on the high stakes tests. Consequently, they are less likely to use inquiry-based activities which require more time, resources, and thought on the part of the teacher. However, with support, such as that provided by the ISMAM project, and beginning small with few, guided inquiry activities, the teachers can adopt inquiry teaching. A final challenge was establishing key performance indicators for project objectives, especially for student learning. This was particularly difficult since we worked with different academic disciplines, schools, school districts, and grade levels. As a result, it was difficult to establish control groups. Moreover, the state content tests did not coincide with some of the participating grade levels.

Conclusion

Based on reports of independent evaluators the project was successful in achieving its objectives and we propose that it can serve as a model for faculty interested in initiating community engagement with K-12 schools. The project involved a large number of participants (38 per year) and had a budget of about $1.5 million over a three-year period. This kind of funding is not possible for most universities. However, the model can be scaled down to more affordable and sustainable levels, while retaining its core implementation strategy of a three-person team: a K-12 teacher, college professor and college student. Thus, an institution could even start with one team and a modest budget for materials and supplies to develop project activities and provide a stipend to the student on the team. An office of community outreach or regional stewardship can assist the team with some of the administrative work such as purchase of materials and guiding the student through processes such as mandatory background check required before one can work in K-12 schools.

The model also serves to demonstrate to faculty how service activity can be connected to scholarship. Whereas the main focus of the project was service, some teams incorporated research (honors theses), publication of journal articles, and presentation at professional meetings in their activities. This is an important element of the model since faculty sometimes shy away from time consuming service activities in order to focus more on scholarship, which tend to be recognized more by reward systems in universities.

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