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Engineers as Inquiry Practitioners*

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The goal of this paper will be to describe Project STEP, the importance of using inquiry-based learning methods to enhance student learning, especially when teaching urban high-school students, and the training involved in teaching engineers to teach using these techniques in under-resourced classrooms. Special attention is given to describing the impact on engineers who were transformed through teaching and learning education coursework and their experiences in these classrooms.

Keywords: inquiry-based learning; inquiry practitioners; transformative education.

INTRODUCTION

WE LIVE IN a world of rapidly changing technology, knowledge explosion and globalization where there is a shift in the type of workforce needed for the nation to remain technologically competitive. To produce a workforce prepared to inaugurate learning, innovating and creating for themselves, our nation needs to more thoroughly educate our children in science, technology, engineering, and mathematics (STEM skills). To accomplish this, teacher training and ongoing professional development for science and math educators is essential for teachers to stay abreast of scientific advancements. American students are not being instructed on a sufficiently compelling level to inspire interest in scientific and mathematical concepts. Creating innovative lessons that will inspire an MTV generation is imperative to revive interest in STEM topics. As a response to these needs, the Colleges of Engineering and Education collaboratively obtained a three-year NSF GK-12 grant to promote Project STEP (*S*cience and *T*echnology *E*nhancement *P*roject), to educate, nurture, and encourage science, and math education.

Project STEP connects engineering students with middle and high-school science, math and technology educators to help bring authentic, hands-on, inquiry-based learning activities into the classroom. Over the course of the three-year program, 16 graduate and 8 undergraduate Fellows have worked with 33 teachers distributed throughout four urban and three suburban schools in three school districts in the Greater Cincinnati area. Fellows and teachers have implemented over 40 different activities in core curriculum classes, including physics, biology, chemistry, forensics, introduction to engineering design, environmental science, integrated math I & II, and geometry. These activities are detailed at the project website (please see http://www.eng.uc.edu/STEP/overview).

Project STEP aims to produce scientists, engineers and secondary science and mathematics educators who are experienced in developing, implementing and assessing authentic educational activities into current secondary science and math curricula. Fellows bring their technical backgrounds and expertise into classrooms and are paired with experienced teachers so that the students can be effectively engaged in STEM-related activities. STEP also aims to impact student learning by relating science and math to community issues through the use of hands-on, technology-driven, inquiry-based projects. These projects focus on city-oriented problems such as transportation, building design, and product development, while authentically teaching STEM skills in curriculum standards. In order to accomplish these goals, teams composed of UC faculty, Fellows, and teachers are formed. Through collaborative efforts, teams are able to share areas of expertise and create quality activities that increase student interest in STEM topics.

In the first two years of the NSF grant, STEP targeted suburban and urban schools where Fellows were able to reach a broader range of students. In the past year STEP streamlined its resources in the Cincinnati Public School district, where a majority of the students are under-resourced and minorities. Of the four schools with which STEP is currently partnered, two have at least a 90% African American student population, while the other two have approximately 65% African American and another 30% who are of Appalachian descent. Research focused on minority achievement and learning clearly indicates the need for more diversified teaching strategies to be utilized. Traditional classes primarily dependent on lectures and regurgitation of information do not increase the content knowledge of these students, nor do these classes increase interest in STEM topics. Our goal was to create classrooms with hands-on, inquiry-based activities to do both. It was imperative for STEP teams to

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develop lessons that would connect with a diversified and under-resourced audience.

INQUIRY

Inquiry is defined as a 'multifaceted activity that involves: making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical thinking, and consideration of alternative explanations' [1]. This practice, although complicated, is one in which the students are actively engaged in their own learning. Although there are many similarities to traditional laboratory activities, inquiry requires the learner to think on a deeper level, thereby acquiring content knowledge and thinking and processing skills.

Teachers shifting from a direct instruction model, in which lecture, demonstrations, labs and research papers are the primary sources of knowledge enhancement, are often startled by the demands of the inquiry method. The teachers must first undergo a fundamental shift in their philosophical framework about teaching and learning [2]. This is not to say that lectures and traditional labs are not valuable tools. However, teachers desiring to focus on inquiry need to reallocate class time to adjust for the deeper involvement of the students that is necessary to successfully complete inquiry activities. With fewer activities presented during a course, several curriculum goals need to be addressed concurrently. In order to address multiple concepts at the same time, the teacher must reorganize notes and activities, frequently a daunting task.

Instructors also must develop new lesson/classroom management strategies in order to engage a diverse population of students. Lectures generally only require students to copy notes and memorize facts and concepts, while inquiry principles require the engagement of every student. Inquiry lessons could easily become a management nightmare if strategies are not put in place to circumvent the possibility of off-task behavior. Inquiry instruction also requires the educator to incorporate more critical reasoning, problem-solving challenges, and processing strategies for the student. While developing higher order thinking skills, the teacher must focus on the best questions to guide the student without giving away the 'right' answer. In inquiry lessons there is not always one correct answer to the problem. Students are required to construct their own knowledge based on their previous understanding, which could be different for each student. In order to develop these complex activities it is critical for the instructor to have direct experience with this instructional modality and to continue developing the process in order to master the method [1]. Typically teachers have to undergo extensive training in order to understand, develop and implement inquiry lessons using this theoretical framework [1]. The methods used to develop the skills of the STEP Fellows are explained in the training section of this paper.

Although there are some differences in the various models of inquiry, it is clear that all models begin the investigation with 'a question about an unusual and intriguing observation of nature' [1]. A primary model of inquiry is called the 'learning cycle'. It contains common components shared by all models. However, within the learning cycle there are three different types of learning cycle lessons. The learning cycle is typically portrayed as having either three or five phases. The three-phase cycle engages the students in exploration, invention, and discovery. Exploration is defined as unstructured experiences in which the students are given the opportunity to explore new materials and ideas with minimal guidance [3]. Introduction or invention is characterized by the students' interpretation of the new information and beginning to restructure previous knowledge and thinking about the concept. And finally the application or discovery phase is defined by the students applying the new concept(s) to an original situation [8].

In the five-stage model, also referred to as 'the 5 Es', the phases are classified as engagement, exploration, explanation, extension and evaluation. In this model the instructional phases are more clearly structured, rather than implied as in the previous learning cycle. The engagement phase focuses on capturing the students' attention through a stimulating activity that is grounded in previous knowledge. The exploration phase is characterized by the students being given time to think, plan, investigate, organize and collect data. In the explanation phase students are expected to analyze their data and support their hypothesis with evidence. The extension phase provides the students with the opportunity to expand and solidify their understanding and apply it to a real-world situation. And finally, in evaluation the instructor generates scores and evaluative feedback usually based on curriculum standards and rubrics. Whether one is using the three-phase model or the more elaborate five-phase model, it is clear that instructors are expected to utilize all components in order to guide learning.

Within the different phases of the learning cycle there are three different types of lessons that 'represent differing points along a continuum' [3]. Although each type of lesson goes through all phases of the learning cycle, there are differences in the degree of critical thinking the student is required to undergo. In the *descriptive* learning cycle lesson, students describe what they are learning with minimal attempts to explain the phenomenon. In the *empirical-abductive* type of learning model, the students are expected 'to go further by creating possible causes of that pattern' [3]. This requires students' to transfer concepts learned in other contexts to the new situation. And finally, in the third type of learning cycle, employing *hypothetical-deductive* lessons, students create alternative explanations to the phenomenon and develop alternative hypotheses. This third type of learning cycle is the one most closely aligned with inquiry instruction. Just planning a learning cycle lesson does not mean a teacher is necessarily teaching inquiry. The teacher must be able to take the lesson to the next level, where thinking and problems-solving skills are necessary to complete the activity. These complex teaching and learning strategies were carefully taught to the Fellows in order for them to be able to develop and implement these types of lessons.

During Project STEP a Fellow created and presented a lesson to a group of high-school students that makes clear the three differing learning models. He posed a scenario and asked the students to solve this dilemma: 'The City of Cincinnati is planning on renovating the transportation system in a suburb. What types of improvements would be the most cost efficient and desired by the people living in that area?' The students were given the construction costs in order to develop three different modes of transportation, paved roads, a light rail system, and bridge development, with three different localities of transportation needed. The students were also expected to take into account the attitudes of the people living in the suburb. In the descriptive learning cycle students calculated and chose the most appropriate types of transportation for the three different localities and described why they chose these. In the empirical-abductive model, students were required to complete this step and also explain why the road patterns were laid out in this manner. The map could include environmental factors found in this particular area. And finally, the hypothetical-deductive lesson expected the students to create at least one alternative transportation pattern for the suburb (see http://www.eng.uc.edu/STEP/ for more details).

There are several implications for inquiry-based instruction that should be noted. First, inquiry is a complex and difficult learning strategy for which a teacher must make the time to train his/her students. Critical thinking skills and learning processes require a concerted effort in order to find ways to think differently than traditional memorization techniques. An inquiry lesson requires much more class time than a more traditional lecture-style lesson. Teachers must plan time into their curriculum in order to support the students in learning these higher-level thinking skills.

It is also noteworthy that, even though inquiry develops essential learning processes, it is not necessarily beneficial to incorporate inquiry into each and every lesson. Finding other techniques that enhance and engage students can also be beneficial for learning. For example, if teachers took the time to understand multiple intelligences [4, 5] and learning styles [6], more students would succeed in the classroom because their needs would be more likely to be addressed [7]. It is worth noting that just because a teacher uses inquiry does not mean that students will understand the concept. Careful planning and preparation are essential in the development and implementation of an inquiry lesson [8]. Each student constructs his/her own knowledge based on previous experiences in and outside of the classroom. This knowledge can be used to trigger schematas in order to code information into long-term and short-term memory [9]. Using cooperative learning groups is also a useful teaching strategy commonly found in inquiry-based instruction. Students with different knowledge levels and experiences can assist others in their group in order to grasp difficult concepts and develop hypotheses. In order to prevent the high achiever from doing all the work, roles are assigned to each group member, while each student is held accountable for his/her work within the team.

Hands-on, student-centered activities are the basis of inquiry. However, it should be noted that just because students are using their hands does not make the activity inquiry [8]. Teachers must create opportunities for the students' to understand the content while being engaged in the activity. Finally, it is important to note that inquiry, as a teaching tool, has grown in acceptance over the past decade and infiltrated the curriculum standards on a national level as well as state-wide. The complexities of teaching inquiry remain, but through research-based education courses, teachers, Fellows or anyone can learn to teach using critical thinking skills to increase interest in math and science concepts [1].

TRAINING ENGINEERS

As inquiry methods are very complex, it was essential to incorporate extensive training for the Fellows, especially because they had little or no experience with the inquiry method. Seven of the eight current Fellows come from engineering undergraduate and graduate programs, while the eighth has a Master's degree in biology. Typically Engineering and Arts & Sciences colleges do not tend to teach the use of research-based educational techniques in their classrooms. Oftentimes professors feel justified in using the lecture as the basis for their courses. However, this means that their teaching techniques are often not in alignment with sound educational practices especially as a model for effective high-school instruction. It is necessary to bridge the gap between proven educational methods and typical higher education instructional approaches. Project STEP accomplishes this by having engineering graduate students learning teaching strategies, with the expectation that this experience will influence the way they teach college courses when they become faculty members. The Fellows are trained scientists and at the same time they are learning about best education practices. A second benefit is that middle and high-school teachers are learning about engineering and advancements in science, math, and technology.

High-school teachers typically spend one to two years completing lower-level college science or mathematics courses as compared to our Fellows, who spend a minimum of four years in their major. Teachers are only required to learn one level above what they will be teaching their students. This minimalist science or math background allows teachers in an ever-advancing field little opportunity to stay abreast of current scientific advancements. On the other hand, teachers spend a minimum of three years completing education coursework, where they learn how students learn and effective teaching strategies. While the Fellows are in tune with their area of academic study, they sorely lack the teaching strategies to be effective instructors in middle-school, high-school or college classrooms.

As a prelude to STEP classroom impact, it was imperative for the 'best Fellows' to be selected. Project STEP looked for scientists and engineers who were open to learning about educational research and willing to implement these teaching strategies. The hiring process was quite extensive. The first phase involved the potential candidate submitting an online application along with two reference letters, transcripts and GRE scores to the project coordinator for initial review. Once the candidates where narrowed down, the Primary Investigators (PIs) determined the best scientists to interview. The potential Fellows were then expected to participate in individual interviews, demonstrate their teaching skills by teaching a ten-minute lesson, and conclude with a silent group activity designed to demonstrate teamwork skills.

Once the Fellows were hired and the Fellowship expectations were explained to the new hires, they enrolled in a summer course at the University of Cincinnati called Instructional Planning, which was taught by the grant coordinator. The Fellows were provided with guidance in instructional approaches and best teaching practices through two textbooks—*Learning and Teaching Research-Based Methods*, fourth edition, by Kauchak and Eggen [8], and *How People Learn: Brain, Mind, Experience, and School*, expanded fifth edition, by John Bransford *et al.* [10]—participation in seminars, and participation in authentic high-school science and math activities. Readings and discussions focused on learning and teaching strategies were deemed not sufficient to provide the Fellows with the necessary skills to develop, implement, and assess lessons based on STEM concepts. Hence, the Fellows also had the opportunity to participate, 'as high-school students,' in a variety of science and math lessons focused on the various teaching strategies that are employed by effective educators. By the end of the course, the Fellows were required to develop and teach three authentic, hands-on, standards-based lessons, with a minimum of one lesson utilizing inquiry techniques, to the other members of the class. The final lesson was video-taped in order to be reviewed and reflected upon. At the conclusion of each lesson, discussions ensued in order to reflect on the positive points of the lesson and to identify areas which needed improvement. Each Fellow was expected to revise his/her lessons based on comments and reflect on why these changes were made. And finally each Fellow was expected to continue learning and improving upon his/her teaching strategies so that in a couple of weeks they would feel prepared to coordinate with their teacher to develop, implement, and assess the STEM-related lessons that they created.

During the course of summer term, the Fellows were also required to learn Dream Weaver, a computer software program designed for the development of personal web pages. Fellows then spent a significant portion of their time creating their own websites in which they would store their portfolios. This was further developed in fall and winter quarter coursework.

During the fall quarter, the Fellows participated in another University of Cincinnati course called Field Practicum. This course focused on the development of portfolios which include lesson plans, handouts and answer keys associated with the lesson, rubrics, a reflective component concentrating on the positive results as well as areas that need improvement, pictures of the students involved in the activities, a philosophy of teaching methodology, a biography of themselves, and any conferences that they attended. The course not only focused on lesson plan development and implementation, but other teaching challenges that the Fellows faced working in an urban school district. Classroom management, school policies, curriculum standards, ethical issues, assessment of student learning, team building, as well as a variety of other topics were discussed on a bi-weekly basis. As the group members were developing into a team, we also determined the importance of learning more about ongoing research related to the fields of the PIs. The PIs attended meetings with the Fellows in order to share their areas of expertise so that their scientific background could serve as a resource for the Fellows' lesson plan development. As the Fellows became more confident in their teaching abilities, the focus began to shift from a 'survival mode' to one in which student learning became the primary concern, it became evident that teaching strategies were becoming honed and perfected. Throughout the fall quarter and into the winter quarter course, Instructional Technology Across the Curriculum, and the spring course, Instructional Teaching/Learning Styles, the grant coordinator continued to provide support for lesson plan development, to observe and evaluate the Fellows' teaching in the classroom, and encourage the use of educational strategies. As various needs presented themselves, these were addressed through development of technology workshops, showcases and open houses in order to disseminate the impressive inquiry-based lessons that were being produced. Through ongoing education courses, the Fellows continued to improve their teaching skills while developing effective inquiry lessons.

IMPACT ON ENGINEERS

Learning to teach is an ongoing process that never fully ends. As continued support is given to the Fellows, more learning takes place. But it is evident that several important changes in their understanding of teaching and learning as well as urban education have been accomplished through their involvement in urban schools. The grant coordinator explained and gave examples of typical situations of the students in urban schools, but the Fellows could not comprehend the effects of the social and economic issues that CPS students face. It is one thing to tell someone about a situation, but something completely different for them to experience it. One of the initial shocks for all of the Fellows was the failure of students to complete their homework on a regular basis. All of the Fellows are achievers and could not comprehend students failing to even attempt homework assignments, which is what they regularly encountered.

All of the Fellows were flabbergasted when the students were rude and disrespectful to the teacher and each other. Fellows are in a very different role to typical student teachers or teaching assistants. The Fellows are considered resources to the teachers, not disciplinarians or future teachers, so when students acted out, they were unsure of how to handle the situation. Through discussions in the university coursework, weekly report venting, and discussions with the teachers, difficult situations in the classroom diminished. A couple of difficult situations also arose with the Fellows when a female student discussed their absence from class due to pregnancy and abortions.

Oftentimes middle and upper socio-economic people have no idea what it is like to live in an urban environment. The realities that face the under-resourced are not even something that one can fathom unless one is in constant contact with them. There tends to be a level of mistrust for authority figures, especially caucasian ones. Just a couple of years ago Cincinnati was faced with a riot in the streets. To some this may appear exaggerated, but to those living in the 'ghetto' this is a real concern in their everyday lives. Fellows had to learn to put themselves into the 'students' shoes' and understand where they were coming from in order to teach them math or science. One Fellow went so far as to develop a lesson based on cosmetology because all her female students had no interest in geometry and could not figure out how they would apply it to their lives. Over 30 mannequin heads were brought to class so the students could participate in the geometry of hair lessons (see http://www.eng.uc.edu/STEP/ for more details). One of the Fellows is of African American heritage and even he was shocked at their lack of respect for teachers and their 'inability to complete homework.' Learning through experience has changed the lives of these Fellows for ever.

Although the eight Fellows this current year were chosen from amongst 70 graduate applicants in the university, each Fellow's ability to communicate effectively with people of all ages dramatically increased. As part of the Fellowship responsibilities for the grant, the Fellows were required to assist in the development and implementation of the Family Science Academy Workshop during the summer. Fourth and fifth graders, along with family members, were given the opportunity to participate in an inquiry-based activity. The Fellows worked together to brainstorm ideas for the development of the lessons and decided on building air-blown vehicles. The fourth and fifth graders were given the opportunity to develop anything they chose based on equipment available, the information about air discussions and various other factors. The winners took home prizes for categories such as the most creative vehicle and the vehicle that traveled the farthest.

The largest change in the Fellows was the ability to create, implement and assess authentic, inquiry and standard-based lessons. In the beginning they struggled to find lessons that would appeal to the students that were structured around a chosen theme, 'the city'. However, as they began developing the lessons with teachers, the grant coordinator and with each other, the lessons became more and more impressive. The Fellows began to understand the complexities of teaching to a wide variety of learning styles and knowledge levels and created lessons accordingly. One of the Fellows also began teaching college students with his adviser in the College of Engineering and has begun implementing some of the questioning strategies in the college classroom. He has reported how shocked the students are by his teaching style, but that they appreciate the change from previous lecturing formats. Other unanticipated outcomes may well continue to unfold as the Fellows develop as teachers.

CONCLUSION

Interest in scientific and math disciplines are declining and our nation's children are falling behind in science, technology, engineering and mathematics (STEM) skills. To remain competitive in a world of rapidly changing technology and globalization, a technologically savvy and broadly educated workforce is needed. Through Project STEP many urban students have been exposed to STEM concepts, especially engineering concepts, to which they would not normally be exposed. Through these efforts students have at the very least gained an understanding about what engineers do, increased their interest in STEM-related concepts and, most importantly, the students have developed the necessary critical thinking skills that will empower them in the workforce.

STEP has also significantly impacted the lives of future engineering and science and math faculty. The Fellows are engaged in research-based education strategies and have experienced first hand how these techniques impact learning. Inquiry-based learning is a difficult skill to develop, but through extensive training the Fellows' have been able utilize these techniques and significantly impact student content knowledge and learning.

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