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Teaching Teachers to Design and Conduct Experiments

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ABSTRACT: *Recruiting more and better-qualified students into engineering programs is a priority of many institutions. The University of South Carolina's College of Engineering and Information Technology has addressed this issue by engaging high school teachers in the research programs of the college faculty. The goal is to increase the teacher's ability to design experiments and to conduct research. With enhanced inquiry skills, they are better able to teach these concepts to their students. In the past two years, two cohorts of teachers each spent six weeks on-campus working with faculty and graduate students on research on the use of fiber reinforced polymer composites in the repair and rehabilitation of bridge beams and columns. The teachers learned to conduct literature research in the library, to design experiments, to fabricate composite material overlays on bridge structure components, to test their materials, and to report their results. The teachers also developed several laboratory modules that were derived from their research to take back and use in their classroom. An evaluation of the teachers' experiences indicates that the program improves their ability to design experiments and conduct research*

1 INTRODUCTION

The Learning Cycle [Bently 2000] is a four-step model proven successful at introducing students to new information, especially scientific lessons. The four steps are Introduction, Exploration, Concept Development, and Application. The Learning Cycle is a core notion in constructivism theory and is an extension of Piaget's Theory of Intellectual Development [Bently 2000]. The premise is that the learners "do not simply mirror and reflect what they are told or what they read. Learners look for meaning and will try to find regularity and order in the events of the world [Von Glasserfeld 1984]." Here, the Learning Cycle was used to improve teacher's abilities to design and conduct experiments.

During the Introduction step of the Learning Cycle, the teachers were given a need to design and conduct experiments. During the Exploration step, the teachers began to experiment by varying parameters and assessing the results. During the Concept Development step, the professor works with the teachers to help them improve their experimental skills. During the Application step, the teachers take what they have learned about how to design experiments and transfer that to teaching their own students.

The research program that provided the basis for this work was funded by the National Science Foundation. The program investigates the use of fiber-reinforced polymer composite materials (FRPs) to strengthen and stiffen in-service highway bridges. For the past two decades, FRPs have been introduced to the construction industry as a practical way to improve the load carrying capacity of our civil infrastructure. For example, fiber reinforced composite materials can strengthen and stiffen concrete bridge decks, in service. However, research is needed to improve the durability of the bond between the FRP and the concrete substrate. For example, if the FRP is impacted, then the bond to the concrete can be damaged and the reinforcement will become ineffective. Hygrothermal environmental cycling can damage the bond between the composite and the concrete, steel or wood substrate.

Two cohorts of five teachers each have participated in this program to date. Each cohort of teachers spent six weeks on the University of South Carolina campus, conducting research in the College of Engineering and Information Technology. In addition, the summer program included field trips, lectures, group discussions, report writing, and help in creating educational materials derived from the research project for use back in the teachers' high schools. Further explanation of how the research program was utilized in each step of the Learning Cycle to develop the teachers' experimental design skills is described below.

2 THE INTRODUCTION STEP

During the Introduction step, the teachers were introduced to the process of how to design experiments. This started with an introduction to the research objectives and the laboratory environment through a lecture, a tour of the facilities, and an informal discussion of their project. The teachers were given very broad research objectives. The first year, the teachers were asked to determine what factors affect the strength of the bond between glass-epoxy composites and wood. The second year, the teachers were asked to determine the effects of rubber toughening and mechanical impact on the effectiveness of composite-wrapped concrete columns. In each case, a number of variables to investigate were suggested to the teachers, but they were charged with choosing which ones to investigate. After three days of self-directed literature- and internet-research, each teacher selected a number of material conditions to study that were of interest to them and of value to the research objectives. This was the key point, relative to developing their experimental design skills. By having the opportunity to select the parameters of their own investigation, they took ownership of the project from the onset. Whether or not they selected "the best" set of variables to examine did not matter. They had selected something that they thought was interesting to investigate, and had become introduced to the process of designing experiments.

3 THE EXPLORATION STEP

Over the next five weeks, the teachers applied fiber-reinforced composite materials to substrates of either wood (cohort 1) or concrete (cohort 2), exposed them to various environmental conditions or mechanical damage, and tested the materials and analyzed the results. They began to experiment by varying parameters and assessing the results. During this step, they were exploring two things. The first was obvious to them: they were exploring the use of fiber reinforced composites in civil infrastructure. The second thing that they were exploring was not made explicit: they were exploring the process of designing and conducting experiments. The teachers would get results, and then use those results to decide what to do next. They had to develop test protocols and sampling methods so that they could get statistically significant results in order to compare test variables. This is the exploration step of the learning cycle. Each time they learned a little bit more about how to design an experiment to get better results.

4 THE CONCEPT DEVELOPMENT STEP

In this program, the concept development steps occurred iteratively with the exploration step. Every day, the teachers and the professor discussed what they were doing, learning, and how well their experiments were going. After analyzing the results, the teachers often obtained results that they did not understand. Through the process of explaining to the professor what they had done, and by discussing what they had learned, the teachers were led to discover what was wrong with the experiments they were designing and performing. For example, they may not have controlled all of the relevant test variables, or may have varied too many at one time to formulate a conclusion. Of course, the professor could have given them a well designed protocol to follow and these mistakes would not have been made. That would have been most efficient if the only objective had been to contribute to the professors' research. However, the professor was guided by the proverb:

Tell me and I'll forget / Show me and I'll remember / Let me do it, and I'll understand.

The professor let the teachers make their own mistakes and successes so that each could construct, in his or her own mind, the concept of the experimental design process.

5 THE APPLICATION STEP

During the Application step, the teachers design experiments for their own students to complete back in high school. This was formally accomplished during the last week of their tenure on campus, although most of the ideas for their lesson plans were developed and refined over the course of their research period. Some of the lesson plans dealt specifically with the composite materials that they had become educated about. However, most of the lesson plans addressed the development of higher-level thinking skills in their students. These include how to examine data for experimental process variability, or how to conduct research. Two of the participating teachers gained enough confidence in their abilities to design and conduct experiments to create new high-school course about research methods.

6 PROGRAM ASSESSMENT RESULTS

The effects of these experiences were evaluated though focus group research. The focus groups were a qualitative researcher from the University of South Carolina's Office of Program Evaluation. The focus groups were conducted at the end of each summer program to elicit the teachers' opinions regarding the research experience and how it might impact their teaching methods and content. The results of the focus groups for the first cohort have been discussed [Lyons 2004], so only the second cohort's feedback is provided here.

The teachers were asked what they gained or learned from participating in this research experience. They discussed a variety of benefits. Two had participated in the program the previous year, and although the research experience itself was not new to them, in the second year they experienced a new level of confidence in the activities involved, and with the research process as a whole. In addition to simply having a level of comfort with the physical surroundings and people within the program, second year participants commented that they were more comfortable with the uncertainty involved in designing and conducting experiments. One of the second year participants stated that "this year I felt comfortable not knowing the answer. Finding more questions instead of finding the answers, which is really what researchers do." Both participants felt that a second year of participation was beneficial, and that they more completely and confidently engaged in the research process. Three participants had just finished their first year of participation. For two of these, this was the first time that they had viewed the research process "from start to finish". They viewed this as "their" research project and not the property of a professor or another researcher. Additionally, one participant mentioned a new understanding of the different fields of engineering, and the tools involved in engineering experimentation. Another participant commented that the experience offered a closer look at the graduate school process, and that the close contact with graduate students and activities allowed for a better understanding of graduate studies which could be communicated to K-12 students.

The teachers were asked how this experience compared to any previous research experiences in which they may have participated. Because the backgrounds of participants varied, responses here were highly individualized. One common theme, even from those participants who had prior research experiences, was a sense of ownership over the process. One participant with a substantial research background commented that "I found it rather satisfying from (the) standpoint (that) we were given kind of a broad range …it was more open then any of the research problems I've had in the past. Usually you extend work that has already been done, but here it was like – start from scratch." Participants' ability to be active in the entire research process and to interact with the problem at all stages emerges as a frequent positive comment. Two participants also commented on the team aspect of the summer experience, mentioning the ability to gain different perspectives and work in the same way that research is done "in the real world". Another benefit of the team concept that was highlighted was the ability to network with other science educators. This allowed participants to develop a sense of what is occurring in other schools in the area. This networking may also result in a type of "support network" through which ideas and information relating to the research continues to be propagated. The ownership of the research process gained in this summer experience, and the relevance of the research conducted also likely will impact the classrooms of participants. Two participants commented on the desire to bring real experiments to their students, allowing secondary students the same type of ownership over the research process that the teachers experienced. By allowing students to generate the research question, find the resources and conduct and report on the experiments, teachers are planning to translate the research experience directly to the classroom.

The teachers were asked to comment on the level of faculty guidance from faculty mentors during the project. Comments on this question were uniformly positive. Participants felt the professor was available when they needed assistance, but that he allowed them the freedom and opportunity to develop ideas independently. Comments included "He treated us as if we knew as much as he did" and "He wanted to see if we would figure it out on our own". The level of interaction was judged as ideal by all participants, and no negative comments were given. Participants also commented that they felt they received support from not only the professor, but also from the graduate students in the lab. The willingness of others in the research environment to share resources and ideas enhanced the experience for participants, and allowed them to participate in the research process as it occurs in a research facility.

The teachers were asked in what ways the experience with this project might affect their teaching next year. One participant reiterated that this experience would allow "real data" to be used in the classroom, instead of using imaginary examples, or those examples taken from a text. This was reinforced by two other participants who discussed the actual props they would take back to their classrooms this fall in order to stimulate discussion on specific topics. Another participant felt that one of the most important things that would transfer to the classroom was an understanding of what it feels like to be a "frustrated student". The participant had little experience with many of the terms and concepts at the start of the project, and as a result felt behind the group. The participant felt this frustrated feeling would actually be beneficial, and that enabled sharing with students that "You don't have to know everything to do research".

The teachers were asked what they thought were the most positive elements of their participation in this program. A wide variety of responses were made. One participant commented that actually conducting the experiments (e.g. breaking the columns) was exciting, and would facilitate discussions that would engage students in the coming year. Another participant stated that learning to use the different equipment in the laboratory setting and exposure to the variety of machinery available in engineering research and testing was the most positive element in the experience. A third participant added that it was "neat" to be in the environment of an engineering building. Positive elements mentioned in response to prior questions should be considered here, including elements such as team membership, ownership of the research process and the development of lesson plans and concepts that will transfer to the secondary classroom.

7 CONCLUSION

The Learning Cycle was combined with advanced materials research to develop the experimental design skills of two cohorts of high school science and mathematics teachers. The teachers worked together as a team to plan and conduct experiments within a research framework that was provided by a professor. Based on the results of independently-conducted focus group evaluations, it can be concluded that this research experience was effective at improving the teachers' abilities to design experiments and conduct research. The experience also motivated them to use more student-centered learning techniques in the classroom

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