Obstacles and Barriers to the Implementation of Engineering Education Coursework in Rural K-12 School System

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Abstract – It is the purpose of this study to examine the interactions of a collaborative group of K-12 and University practitioners and researchers in the implementation of engineering educational programs in rural K-12 school systems, where learners are more likely to benefit from collaborative learning experiences and less likely to be exposed to the engineering profession through peer groups and role models. The researchers found that rural school systems offer a unique set of obstacles and barriers to the implementation of engineering education that require a greater manipulation of the environment than found in urban and inner-city schools. Presented using the imbedded multiple case study methodology, the study examines the issue from the perspective of the classroom teacher, in-service educational specialist, instructional designer, university researcher, and educational administrator.

Keywords: rural, case study, K-12, instructional technology

INTRODUCTION

K-12 school systems can be categorized as urban, inner-city, and rural. Learners from each group exhibit discernable differences in problem solving approaches, peer groups, role models, gender, and family values. These differences play a role in the expansion of K-12 engineering educational programs by defining a cultural basis for instruction that is more likely to meet program goals and objectives through a *situated cognition* approach to instructional development [Slavin, 5]. Situated cognition defines a dimension of learning as a reflection of the school environment.

Engineering educational programs often attempt to modify K-12 environments by introducing newer approaches to education designed to inform and attract learners to the engineering profession. Often these efforts include exposure to the engineering vocation through interactions with role models in the form of practicing engineers and other formal engineering groups. Unfortunately, the engineering role models that support these approaches to learning and the resources they bring with them are normally located in larger metropolitan areas. While urban and inter-city school systems are easily accessible to these groups, rural school systems are somewhat removed from immediate service areas of most engineering groups, making engineering education programs more difficult to implement. Compounding the issue is the instructional gulf separating engineers and K-12 teachers resulting in a steep learning curve associated with defining parameters of engineering education within the highly structured K-12 system for both groups.

The researchers found that rural school systems offer a unique set of obstacles and barriers to the implementation of engineering education that require a greater manipulation of the environment than found in urban and inner-city schools. Presented using the imbedded multiple case study methodology, the study examines the issue from the perspective of the classroom teacher, in-service educational specialist, instructional designer, university researcher, and educational administrator.

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BACKGROUND STUDIES

Employment opportunities in the U.S. requiring science, technology, engineering, and mathematics (STEM) expertise are growing rapidly. From 2010 to 2020, the growth is expected to increase about three times faster than the rate for all other occupations. However, the available domestic STEM labor supply has not been able to satisfy this growth because of the long-term trend of fewer students' entering STEM programs in college, thus threatening the ability of U.S. businesses to compete in the global marketplace. Responding to this dilemma, the National Science Board has stated that the federal government and its agencies must step forward to ensure the adequacy of the U.S. STEM workforce, and that all stakeholders must mobilize and initiate efforts that increase the number of U.S. citizens pursuing STEM studies and careers [DeReamer, 2].

Despite years of efforts to diversify the STEM workforce, it remains overwhelmingly white, male, and able-bodied, and the available pool of talented women, minorities, and persons with disabilities remains significantly underutilized. If individuals from these underrepresented groups were in the STEM workforce at the same percentage as their representation in the total workforce population, the shortage in the STEM labor supply would largely be filled. Also, the fact that currently underrepresented groups are projected to increase from about a quarter of the workforce to nearly half by 2050 suggests that the U.S. must cultivate the STEM talents of all of its citizens, not just those from groups that have traditionally worked in STEM fields [May, 3].

Many efforts have been directed at increasing the percentage of student populations in the STEM workforce. These include summer and after-school programs for high school students, and the integration of STEM applications into high school curricula. These efforts, which are typically conducted by universities, represent many STEM disciplines, including engineering disciplines. However, little work has focused on integration issues confronting K-12 and university educational professionals during the development process of K-12 engineering education materials. It is the purpose of this study to examine the obstacles and barriers faced by these groups as they develop educational materials for use in a rural K-12 school system.

RESEARCH OBJECTIVES AND SCOPE

It is the purpose of this paper to examine the issues exemplified, over the course of a three year service project, through the development and implementation of engineering coursework through a series of K-12 science courses in a rural high school. The research was guided by four research questions:

1. What technical skills were needed by university and K-12 personnel in the development of K-12 engineering instruction?
2. What modes of instruction were best suited for the delivery of engineering instruction in rural K-12 school systems?
3. What were the professional development needs of K-12 teachers to deliver instruction in engineering education?
4. How would units of instruction be constructed to fit into existing curriculums?

METHODOLOGY

The theoretical basis for this research is phenomenological inquiry, which uses a naturalistic approach to "inductively and holistically understand human experience in context-specific settings" [Patton, 4]. Researchers were most concerned with the specifics of issues experienced by classroom teachers, university professors, and educational support personnel in the implementation of the "Building Alabama" project. Information collection was through combinations of survey and interview data, reported results were verified using case study methodology. The research methodology progressively exposed and untangled the complex authenticity of the subjects involved in the project. Data included transcripts of interviews with each participant, project meeting observations, project artifacts such as e-mails and handouts, teacher lesson plans, and lab exercises developed for the project. Data collection methods and artifacts along with the number of each are summarized in Table 1.

Table 1. Data Collection Methods and Artifacts

METHOD	TEACHER	IN-SERVICE SPECIALIST	INSTRUCTIONAL DESIGNER	UNIVERSITY PROFESSOR	UNIVERSITY ADMINISTRATOR
INTERVIEWS	**5**	**9**	**7**	**9**	**6**
OBSERVATION	**32**	**14**	**34**	**17**	**8**
ARTIFACT-EMAILS	**9**	**12**	**64**	**36**	**21**
ARTIFACT-HANDOUTS	**14**	**8**	**5**	**6**	**4**
ARTIFACT-LESSON PLAN	**16**	**67**	**8**	**0**	**0**
ARTIFACT- LAB EXERCISES	**27**	**84**	**6**	**6**	**0**

As in many qualitative studies, researchers began with a broad question and constructed finer foci as the data were analyzed [Patton, 4]. Concerns of validity in qualitative research were addressed using two techniques: triangulation through multiple data-gathering techniques [Berg, 1]—i.e., interviews, observations, and artifacts—and methodological integrity [Patton, 4]—i.e., participants read and authenticated results of data analysis and early drafts of this manuscript.

An iterative content analysis technique involving transcribing audiotapes, and coding artifacts, observations, and interviews was used to organize participant responses [Spradley, 6]. The unit of analysis was a single topic or a subject. Selection criteria and the categories each subject topic was determined at the end of the second "Building Alabama" project meeting. Data was separated into separate component parts and then integrated into single topic segments. Initial categories included: a) Technical Skills Level, b) Modes of Instruction, c) Use of Engineering Coursework in Classroom, d) Professional Development, and e) Construction of Units/Curricular Planning. No additional categories were added as the work unfolded. Underlying patterns of data were defined and discussed using inductive analysis approaches.

Interview formats with participants were described as "guided semi-structured or semi-standardized" [Berg, 1]. Researchers asked pre-determined questions and introduced special topics. When warranted, researchers probed deeper into participant responses and the participants were encouraged to add additional reflections, comments, or opinions that had not been formally posed. Field notes of observations were reviewed and expanded as soon as possible, and coded into emerging categories of interest.

Criteria for the selection of participants were: active involvement with the "Building Alabama" project, either teach or provide support services in science or engineering, and show a willingness to participate in the research. In addition, participants had to be available for observation during normal hours associated with university meetings and activities. Participants were deliberately chosen among those who had an average level of involvement in the "Building Alabama" program. Individual who were heavily involved and prominently visible were not utilized, and neither were individuals with only a modest connection to the program.

Building Alabama Project

The "Building Alabama" project is a three year service scheme funded by the U.S. Department of Education focused on the incorporation of engineering education into existing science labs. The project partners The University of Alabama and The University of Alabama Regional In-Service Education Center with classroom teachers from six rural counties serviced by the In-Service Center. Representatives from project partners met on a monthly basis to design and implement a series of engineering science labs in physics, chemistry, biology, and mathematics. Labs were then distributed to 30 separate science labs in the service area before adding them to a state-wide inventory of In-Service Center holdings.

Participants

K-12 science teacher**-** The teacher held an MS degree in Curriculum and Instruction with an emphasis in physics and chemistry. She had worked in a rural school system for six years.

In-service Science Education Specialist**-** The science education specialist held a MS in Curriculum and Instruction with emphasis in chemistry. She had worked as a classroom teacher for 15 years in addition to serving eight years with the In-service group.

Instructional designer**-** The instructional designer held a PhD in Educational Psychology-Research as well as an MSIE. He had worked in various community college and university positions related to instruction and had worked on three similar projects previously.

Engineering Professor- The engineering professor held a PhD in Industrial Engineering and had worked on several projects in engineering education at the university level. He had worked in engineering education for more than eight years.

University Administrator**-** The administrator worked as an Associate Dean for Engineering Programs for more than six years. He had worked on multiple projects involving freshman programs.

RESULTS

Technical Skills Level

All participants went into the project with a positive attitude. This created an environment of professionalism over the life of the project which allowed participants to resolve differences without conflict. There was, however, a noticeable lack of technical skills that had to be overcome to ensure group productivity. The classroom teacher and in-service science specialist lacked an understanding of the concept of engineering. This is attributed to the rural nature of the school environment and the lack of engineer role models in the community. Both participants continuously promoted the development of projects that only superficially represented engineering as a discipline.

Both the engineering instructional designer and university professor had sufficient technical backgrounds in engineering but both lacked necessary skills in curriculum development at the K-12 level. The instructional designer had a superficial understanding of a standards based curriculum and a considerable background associated with child development across grade levels. These understandings were not held by the engineering professor.

Initial meetings with teachers indicated that the teachers and in-service science specialists were intimidated with the presence of an educational psychologist. This was determined to be due to a misunderstanding of the role of the psychologist. At the outset, the K-12 participants viewed this individual for his assessment and measurement skills rather than as an instructional designer, this caused the psychologist to be viewed as someone who would sit in judgment of their success or failures with the project. It was later determined that intimidation felt be the teachers was more related to high stakes testing than the psychologist himself.

The organizational skills of the administrator played an instrumental role in overcoming the lack of technical skills held by program participants and in defining the role of the educational psychologist. On their own, the two groups, engineers and teachers, moved in separate and exclusive directions early but were brought together through the formation of groups consisting on one individual from each representative discipline.

Modes of Instruction

Instruction at the university engineering level is delivered substantially differently from that of K-12 classrooms. Engineering instruction is generally delivered to a group of students who have both shown an interest and ability in such programming. These groups of students have a vested interest in a proven outcome and are asked to perform at high levels of achievement. The engineering professor was accustomed to this type of instruction and how it is used to develop advanced problem solving and critical thinking skills.

The focus of the K-12 teacher was somewhat different. In the K-12 classroom, there is a variety of students with a diversity of interests and abilities. The classroom teacher was very aware of this along with a need to develop instruction that both met the needs of all students and prepared students for *high stakes testing* requirements of modern K-12 curriculums.

The two different foci clashed with neither being completely satisfied with the others viewpoint. The professor held the view that the teachers were diluting the instruction and the teacher held the view that the professor promoted classroom materials that were neither relevant to the classroom nor within established state standards. This clash in views was attributed to the lack of understanding by the professor on the nature of learning and cognitive abilities of K-12 students. Differences were resolved through the skills of the instructional designer who was successful in designing instruction acceptable to both parties. The resolution efforts of the instructional designer created an alliance between the teachers and in-service personnel with the instructional designer, reducing, but not eliminating, concerns for the role of the instructional designer.

Use of Engineering Coursework in Classroom

In Alabama, there are no provisions for the inclusion of engineering education in K-12 classrooms. There are, however, structured guidelines for a series of standards to be applied to each grade level. Standards are in place to ensure that students learn what is appropriate at grade-level rather than allowing teachers or textbooks to make that determination. The focus of standards is aimed at a high and deep level of understanding that transcends traditional textbooks or lesson based instruction.

An immediate concern was how to incorporate engineering instruction into existing curriculums in a manner that met state standards. The development groups were able to examine existing instructional materials and incorporate standards through an inclusion approach to development. That is, engineering coursework was aimed at specific standards. This effort had an added advantage of keeping the demands of the engineering professor in sync with the cognitive abilities of the K-12 student. An added advantage was found in that engineering instruction could be designed to appeal to the student at a higher level than previous instruction, making the programming more likely to be adapted by teachers outside of the initial test group.

Professional Development

The issues associated with bringing all participants together were expected to be magnified by efforts to implement the project in the K-12 school system. Researchers begin examining the perceptions of program participants to build an outline of training needs for classroom teachers in the school system. The initial plan to develop an on-line training program was expanded to include on-campus training of teachers and in-service personnel in the implementation of classroom materials. This training included an introduction to the program and tours of engineering research labs and classrooms.

Construction of Units/Curricular Planning

Project materials were organized into lab packets. Each packet contained the necessary equipment and materials necessary to deliver an engineering educational lab to a class of 30. Each engineering lab was designed to be implemented in block, period, or blended on-line format. Labs were restricted to one and two session formats, making the labs more attractive to classroom teachers and limiting concerns with interference with high stakes testing issues.

The latter was a concern to the engineering professor, who insisted that engineering be the primary focus of the instruction. This was an issue that defined the professor’s perception of the project and was never resolved to the professor’s satisfaction.

Research Questions

Research Question One addressed the technical skills required by university and K-12 personnel in the development of K-12 engineering instruction. It was determined that university personnel lacked an understanding of child development, State Educational Standards, and high stakes testing. Original efforts at integrating engineering faculty into the project with the expectation that they would pick up these understandings as they progressed through the project were unsuccessful and resulted in high levels of anxiety within K-12 teacher participants. The gulf between university professors and K-12 was eventually closed through formal training of university personnel.

K-12 personnel initially lacked even basic understandings of engineering. This was attributed to the lack of engineering role models in rural areas. Technical skill development was hampered by misconceptions K-12 teachers held concerning the role of "design" in engineering, with teachers defining the concept superficially. A strategy employed by the project was to expose teachers to engineering through involvement with existing university research projects outside of the "Building Alabama" project. These projects included existing research, classroom tours, and participation in proposal meetings.

Research Question Two asked what modes of instruction were best suited for the delivery of engineering education programs in rural school systems. While engineering colleges have the capability to deliver instruction using advanced technologies, many rural K-12 systems lack the resources to assimilate advanced technology into existing classrooms. The dilemma was manifested with the changing technology capabilities that can quickly occur in school systems, with resources made available with the sweep of a legislative hand. To meet present and future technology capabilities of rural school systems, the project settled on an approach that delivered instruction in multiple formats ranging from pencil-n-paper to interactive software developments. Multiple delivery methods had the added value associated with maintaining current modes of delivery as each school systems technology resources changed, adding increased sustainability to the course materials.

The professional development needs of K-12 teachers preparing to offer engineering educational programming guided Research Question Three. Working from research artifacts (Table 1), project participants formed a three person committee consisting on one engineer, one teacher, and one instructional designer. K-12 teachers across the intended delivery area were surveyed and the results were added to existing artifacts. Committee findings resulted in the development of a summer institute for K-12 science teachers aimed at the delivery of instruction of "Building Alabama" project materials. Initially the institute was a five day presentation that focused primarily on course materials. It was later revised to include a greater emphasis of defining engineering as a profession and on interactions with engineering faculty.

Research Question Four focused on fitting engineering programming into existing educational curriculums. Traditional college prep curriculums have little room for dedicated coursework, resulting in the creation of materials intended as alternatives to existing science lab exercises. This approach yielded an approach implementing engineering instruction across multiple scientific disciplines taught over three years of K-12 study. Given that all labs were incorporated into a students K-12 curriculum, each student would be exposed to more than 40 hours of engineering instruction. As an incentive to encourage K-12 teachers to implement the labs, each lab was specifically designed to incorporate State Standards and was accompanied with an action guide to ensure standards were met.

Discussion

This study examined the issues exemplified with the development and implementation of engineering coursework through a series of K-12 science courses in a group of rural high schools. It defines the facilitators and barriers that five educators from both engineering and K-12 classrooms faced as they implemented the "Building Alabama" project. The initial expectations of the project were that the project would identify creative and innovative approaches to the inclusion of engineering education in to existing K-12 coursework. However, this research documents ways in which program participants experienced the advent of ubiquitous engineering instruction differently, especially representing the interchange between their technical skills, modes of instruction, use of engineering education in the classroom, professional development, and construction of units/curricular planning. For all participants, their views of engineering education in the K-12 classroom were strongly influenced by their beliefs about teaching and learning. Although the case study methodology precludes generalization to larger populations, it provides a reflective opportunity for educators who are considering similar undertakings.

LIMITATIONS AND FUTURE RESEARCH

A recognized limitation of the study is related to the case study methodology in general and a sampling of convenience. The individual character and personal traits of program participants may bias the results in an unexpected and irrepressible manner common to a sample of convenience.

Areas for future research include the perceptions of classroom teachers and students to materials developed through the "Building Alabama" project. Other potential topics include increased communication between K-12 and university educators to include summer research experiences and mentoring relationships aimed at increasing the understanding of engineering by teachers and in-service personnel.

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BIOGRAPHICAL INFORMATION

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Terry Brumback is a research associate with the Department of Educational Studies in Psychology and Research Methodology at the University of Alabama where he teaches quantitative statistics and research methodology. He holds PhD's in Educational Psychology-Research and Instructional Leadership with an emphasis in engineering education. He also holds an MSIE in Industrial Engineering. His research interests include analysis of discrepancies between ability and achievement; linkages between cognition, achievement, and instruction; and Rasche Facet Models in the explanation of developmental processes related to advanced problem solving and critical thinking skills.

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