Integrating First-Year Engineering Design And Pre-Service Science Education: A Model For Engineering And Education Collaboration To Enhance K-16 STEM Education

Carol Crumbaugh¹, Paul Vellom², Andrew Kline³, and Edmund Tsang⁴

Abstract – The purpose of this paper is to describe the emerging results of a collaboration between education and engineering using science activities and instructional devices produced in a specially-designed undergraduate course, Introduction to Engineering and Technology (ENGR 101). These materials were used and evaluated by senior-level education students who then provided feedback regarding the clarity of the manual, the appropriateness of the activities, and the user-friendliness of the activities and devices. The process wherein education students used and assessed the instructional activities is described. In addition, preliminary findings are provided and future work outlined.

Index Terms – Engineering and education collaboration, pre-service teacher education, first-year engineering experience.

INTRODUCTION

Western Michigan University (WMU) was awarded a National Science Foundation Bridges for Engineering Education planning grant in August 2002 to build collaboration between the colleges of education and engineering to enhance K-16 science, technology, engineering, and mathematics (STEM) teaching and learning. An objective of the collaboration was to design and build instructional devices to support K-12 teaching of science concepts. One of the Bridges projects was to take an existing course in the College of Engineering and Applied Sciences (CEAS), ENGR 101, “Introduction to Engineering and Technology,” and create a section for engineering and elementary education majors [1]. To attract education majors, the course could be used to fulfill a science requirement in the elementary education curriculum. This special section of ENGR 101 included course objectives directed toward elementary education majors as well engineering majors. For elementary education majors these objectives included: 1) describing the work of engineers and technologists so that future teachers will be able to advise K-8 students regarding the engineering and technology profession; 2) transforming knowledge of some science concepts by applying it to real-world problems; 3) developing at least one hands-on tool or apparatus for classroom use; 4) creating at least one activity for K-12 students or teachers using the tool/apparatus; and 5) working with Michigan Science Benchmarks to relate real-world applications to the science concepts to be taught with the classroom apparatus or tool. Goals for engineering majors included: 1) gaining a better understanding of the profession they have chosen through engagement in structured learning situations that in some ways simulate problems typical to engineering fields, such as meeting the needs of a client or customer (in this case, K-12 teachers); and 2) developing the foundation skills to become successful in studying engineering and technology.

This paper describes a further collaborative process between education and engineering wherein students in two senior-level education courses experimented with the instructional devices and science activities produced by ENGR 101 students. It presents 1) the process used in ENGR 101 to produce the instructional devices and supporting materials, 2) how education students in EDU 401 and 402 interacted with the devices and materials in order to provide feedback on their usefulness and appropriateness for K-12 classroom use, 3) a summary of the feedback these seniors in teacher education gave after interacting with the devices and materials, and 4) lessons learned about collaboration during this process. The impact of ENGR 101 on engineering student learning and the value added by this unique engineering-education collaboration to learning in ENGR 101 will be the subject of a future paper.

IMPLEMENTATION OF ENGR 101

A challenge in this task involved creating class activities and course materials that met the learning objectives for two diverse student populations. This challenge was partly met by

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1) creating course modules to teach problem solving using examples taken from the K-8 science curriculum, such as friction force, phase change, electricity, energy and energy flow, acid rain, and spatial measurement and navigation; and 2) using the inquiry model of instruction in introducing these concepts to the education and engineering students enrolled in ENGR 101. In the basic inquiry model of instruction, students are invited to learn through a series of exploratory activities in the laboratory in which they manipulate parameters and make observations on their effects. The students then form hypotheses, conduct further investigations, and use the findings to either reformulate the questions or arrive at an understanding of the formal concepts—see Figure 1 [2].

Each of the engineering faculty members developing the course modules was assigned an education faculty member who reviewed the materials and provided feedback. Furthermore, service-learning design projects to build laboratory equipment and instructional devices to support active learning of mathematics and science in K-8 classrooms provided the context for the education and engineering students in ENGR 101 to learn and practice engineering design, teamwork, and communication skills.

**Additional Collaboration Between Education and Engineering**

In Fall 2003, the first semester ENGR 101 was taught, two assignments were selected for subsequent interaction with education students enrolled in two 400-level classes, ED 401, “Teaching Elementary School Science,” and in ED 402, “Practicum in Science and Mathematics Teaching,” during the following semester (Spring 2004). These two assignments were (a) design projects to create instructional devices to study the topics of electromagnetism, and (b) activities to investigate phase change.

The topic of the design project, electromagnetism, was based on the science topics emphasized in a local elementary school where a section of WMU education students serve as pre-interns. The goal of the design project was to produce activities, instructional apparatus, and a manual that the WMU education students could use to lead hands-on activities to study electromagnetism. The guided design project consisted of the following assignments:

1. Exploratory lab “play” to explore the principles of electromagnetism.
2. Perform a web-based literature search using the American Association for the Advancement of Science (AAAS) Benchmarks for Science Literacy, the Eisenhower National Clearinghouse for Mathematics & Science, and the Ohio Research Center to identify the team’s top three choices of activities for a design project and the associated science benchmarks, grouping the activities into two categories of Grades K to 2 and Grades 3 to 6, with at least one activity in each category.
3. Generate design specifications and solution ideas, and evaluate and select one solution idea for implementation, addressing the concept(s) and the data/variables that the instructional apparatus can be used to collect or manipulate.
4. Create a bill of materials, and build and assemble the instructional apparatus.
5. Prepare and make a report, listing the activity, key concept(s), variables or parameters for manipulation, the results of the manipulation, photographs or dimensioned drawings, and a manual.

The topic of phase change was selected because it can be found at several grade levels in the K-8 science curriculum. The goal is to introduce K-8 students to basic chemistry concepts related to phase changes and physical properties. After a short introductory presentation, ENGR 101 students were “invited to play” in the laboratory, to focus on activities involving physical or chemical phase changes: melting/solidification; creating “goo”; making potential volcanoes; dissolution and crystallization; and polymerization. The laboratory “play” was followed by a lecture whereby some general physical properties and terminologies were formally introduced. ENGR 101 student teams were then assigned to propose to the instructor two experiments that they would perform to illustrate key concepts in chemical or physical phase change. In the proposal, ENGR 101 students were required to describe the hypotheses to be tested, the data to collect, and the materials they would need. The ENGR 101 students then performed the
experiment and produced a report describing the hypothesis, the experimental procedure, tabulated and/or graphed data, and interpretation of the data to prove or disprove the hypothesis.

In Spring 2004, the electromagnetism devices and design reports as well as the phase change reports were given to two education instructors (who teach two different courses) who then incorporated curricular activities related to these devices and design reports into their ongoing course work. The education students were assigned to use the instructional devices designed and built by first-year engineering students and to follow the user manuals to perform the mathematics and science activities, and to provide feedback on the appropriateness of the activities, the user-friendliness of the laboratory equipment/instructional devices, and the clarity of the user manual. A description of the experiences of the students in the two education courses with the engineering devices follows.

**ED 401 AND ED 402: WORK WITH ELECTROMAGNETISM DEVICES**

Students in ED 401, a science methods course, are seniors majoring in Elementary Education, and have taken a six-course science sequence prior to enrolling in this course to learn specific teaching techniques and approaches. Course objectives include: 1) utilizing the Michigan Science Benchmarks to plan effective instruction; 2) evaluating, modifying, and using a variety of resources for science teaching including manipulatives and web-based, text-based, and visual media; and 3) identifying safety hazards and issues, and planning or modifying instruction to ensure safety. The devices and user manuals from ENGR 101 provided a unique opportunity for students to focus on what constitutes a good hands-on science lesson by evaluating the manual and apparatus together, and discussing and writing reflective feedback about their experiences. (At the time this report was written, only the examination of the electromagnetism manuals and devices was completed, with the examination of phase change manuals and activities scheduled to take place in March.)

Students in each of four sections of ED 401 (n=94) evaluated the four manuals and related devices. Using a Feedback Form (Figure 2) created jointly by the education course instructors, each student evaluated one apparatus as a part of a group of students doing the same activity. The instructor gave general guidelines to the class encouraging students to work back and forth from the manual to the device, and to pose questions and observe carefully as teammates interacted with the device. Feedback forms and manuals were provided, and students began reading immediately. After approximately 5 minutes the devices were given to each group. The instructor required student-led group problem solving by responding only when a device failed to work properly. Students interacted with the devices and documentation over a period of 30 minutes, at which time feedback forms and materials were collected. A brief verbal response period followed in some sections, allowing students to further process their interactions with the materials.

The Practicum in Elementary Science and Mathematics Teaching (ED 402) is a senior-level course typically taken the semester preceding student teaching. It is a field-based course where students, known in the Elementary Education program as pre-interns, are in classrooms twice a week for a total of eight hours per week. The number of pre-interns who participated in this study is 14. Specific course objectives from ED 402 focused on for the purposes of this study include: 1) learning how to design and develop thought-provoking activity-based science and mathematics units that best facilitate student understanding of fundamental science and mathematics concepts; 2) increasing one’s understanding of important science and mathematics concepts (i.e., build on one’s own conceptual knowledge); and 3) learning to know a wide variety of resources for mathematics and science lessons and mathematical and scientific information.

**Table 1: Clarity of directions for teachers**

<table>
<thead>
<tr>
<th>Clarity of directions for teachers</th>
<th>Desirable</th>
<th>Not desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>When a teacher (you) looks at the manual and apparatus, can you tell what to do?</td>
<td>5 4 3 2 1</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>Are the desired “effects” (what you should see when you manipulate the apparatus) stated?</td>
<td>5 4 3 2 1</td>
<td>5 4 3 2 1</td>
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**Table 2: Usefulness of diagrams**

<table>
<thead>
<tr>
<th>Usefulness of diagrams</th>
<th>Desirable</th>
<th>Not desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are parts clearly labeled?</td>
<td>5 4 3 2 1</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>Does it use language that teachers and students will understand?</td>
<td>5 4 3 2 1</td>
<td>5 4 3 2 1</td>
</tr>
</tbody>
</table>

**Table 3: Guidebook demonstrates relationship to Michigan Science Benchmarks**

<table>
<thead>
<tr>
<th>Guidebook demonstrates relationship to Michigan Science Benchmarks</th>
<th>Desirable</th>
<th>Not desirable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall judgment of how well this would work with students at the designated grade levels.</td>
<td>5 4 3 2 1</td>
<td>5 4 3 2 1</td>
</tr>
<tr>
<td>Is it user friendly? Better than other instruments? Rate it on a scale of 1-5, where 4 or 5 indicate you’d be likely to use this device and scores of 1-3 indicate you wouldn’t use it, due to reasons you list below.</td>
<td>5 4 3 2 1</td>
<td>5 4 3 2 1</td>
</tr>
</tbody>
</table>

**Figure 2: FEEDBACK FORM: ELECTROMAGNETISM**

What went well and why:

What didn’t go well and why

**Specific suggestions** for additions to the manual, reorganization of contents, etc. in order to make it more teacher/student friendly, useful. Use page numbers, refer to specific parts, etc.

1. 2. 3.
Pre-interns were placed in groups and each group was assigned to an electromagnetism device. Each group was to take 5 minutes to read the device’s manual and then experiment for approximately 20 minutes with the device to determine the clarity of the instructions as well as the device’s practical use to teach science content to children, keeping in mind the children in their K-6 classroom placements. Upon completion, each pre-intern completed a Feedback Form for each device. When finished, the instructor led a whole-group discussion that focused on the potential classroom use of these devices.

There are three ways in which pre-interns’ participation in this study differed from that of students in ENGR 401: 1) the number of students [94 science methods students evaluated the engineering devices, while 14 pre-intern students did so]; 2) science methods students each evaluated one device and most pre-intern students evaluated three. [Due to the malfunction of the Electromagnet & Solenoid, there is no feedback from pre-interns students regarding this device]; and 3) the session in which pre-interns experimented with the devices concluded with a whole group discussion.

Examination of evaluation data, in broad strokes, revealed areas of strength in most or all of the user manuals, for example:

- the manual and apparatus together usually made it clear what to do, and written directions were often easily followed
- the desired effects that one should see were clearly stated and (less frequently) easily seen
- in most instances, science concepts were clearly explained

Education students found the diagrams in the manuals difficult to understand, using unfamiliar language or symbols, and difficult to relate to the apparatus. They also rated the user manuals low on relationship to the Michigan Science Benchmarks, and frequently questioned the grade-level appropriateness of the devices and activities. Summary judgments generally supported two of the four devices and their related materials as being sufficiently well done that education students would want to use them in a classroom with students in the 3-6 grade range. (More complete data from this study will be reported in an upcoming paper.)

This set of findings is substantial and potentially important in two respects. First, the findings as written form a cogent basis for a set of recommendations for the revision of instruction in ENGR 101 with future cohorts of students. Clearly labeled diagrams, additional instruction on the Michigan Science Benchmarks, and increased attention to the age and capabilities of children who would use these devices could make future projects work better in educational settings. In some cases, specialized terminology related to using devices to teach electromagnetism to children (particularly in grades K-2 where the ability to read complicated directions is limited) was problematic, and in all cases safety issues must be carefully considered. The second way in which these findings are important relates to the revision of the current projects, so that they can become useful, safe, and motivating tools for classroom use.

**LESSONS LEARNED**

From this work, the instructors of both education courses learned that the work with the devices and their manuals forced their education students to think about content, teaching, and learning in a unique way. In particular, through this experience the education students found themselves confronted by their content knowledge, that is, their knowledge of concepts and facts related to electromagnetism. In addition, they were challenged by their pedagogical content knowledge, which essentially is their ability to meld appropriate content knowledge, pedagogy, and the developmental and educational needs of the children they teach [3,4]. Development of content knowledge and pedagogical content knowledge are seen as important and challenging goals of most teacher preparation programs, and are central foci of education courses at this institution.

One challenge emerged in the process of having education students experience the engineering design projects when one of the devices malfunctioned. As a result, groups were spontaneously reconfigured so that the plan for experimentation with all devices could continue. At least two recommendations for future work emerged from pre-interns’ experimentations with devices. First, the instructor can include a system to track students’ rotation through the use of all devices and their manuals. Upon observation, it appeared that students became more critical of devices and manuals with each additional experience. Because they manipulated, discussed, and reviewed each device and its manual, it is logical that they began comparing and contrasting them in situ. Although an unanticipated outcome, this increasingly sophisticated critique could be a useful learning and feedback tool. Second, future students in the education courses who participate in these studies can be more actively involved in subsequent revisions of devices.

**LESSONS ON COLLABORATION**

An important set of lessons also emerged in relation to the collaboration between students in ENGR 101 and those in ED 401 and ED 402. First, each of these sets of students is enrolled in a course with specific objectives as delineated in an approved syllabus. Thus, instructors for each course were bound by the course description and the way the course fit into the larger academic programs. The resulting collaboration, bound by these constraints, was out of necessity very structured and somewhat limited in scope. We see this as typical of the kinds of accommodations that would have to be made at most universities. Second, the courses in question each reflect the structures, content, and underlying values of the disciplines in which they find their origins. Collaborations across these discipline-based courses often reveal different underlying assumptions, language patterns, and goals – and all of these factors can impede effective
communication in collaborative efforts. In some respects, the education students’ difficulties with some of the materials in this study may have had roots in these differences. Third, collaborations across colleges may reveal the same tensions that exist in school-university partnerships, such as differentials in resources, workload expectations, the way research is formulated [5]. These tensions can subtly undermine efforts at collaboration if careful attention is not paid to recognizing and resolving these differences in ways that respect and value the contributions of each member.

A LARGER CONTEXT FOR COLLABORATION: THE ENGINEERING DESIGN CENTER FOR SERVICE-LEARNING

The project described above is a springboard for further collaboration between upper-level engineering and education students to design and build instructional devices to support K-12 teaching of science concepts. This is made possible by the Engineering Design Center for Service-Learning. Funded by National Science Foundation (award # 0315695) and the Corporation for National and Community Service Learn and Serve America Higher Education grant (03LHHMI001), The Engineering Design Center for Service-Learning provides an opportunity for multidisciplinary collaboration through the creation of three one-credit hour courses at the sophomore, junior, and senior levels (ENGR 202, 303, and 404). It is modeled in part after EPICS (Engineering Projects In Community Service) of Purdue University [6]. The establishment of the Engineering Design Center for Service-Learning will be presented at the 2004 Frontiers In Education conference [7].

FUTURE WORK

In the immediate future, the feedback from ED 401/402 students on the electromagnetism design project will be provided to ENGR 101 students in Fall 2004. The “novice engineers” in ENGR 101 will benefit from the feedback as part of learning about redesign in product development. The intended result is useful instructional devices that will be delivered to support teaching of electromagnetism at a local elementary school. Similarly, the phase change materials developed by ENGR 101 students in Fall 2003 and evaluated by these same education students in Spring 2004 using refined processes as described above will be revised by engineering students in Fall 2004.

By applying the model of collaboration described in this paper, mathematics and science activities, instructional devices, and user manuals created by ENGR 101 students in Fall semester and evaluated by ED 401/402 students in Spring semester, will be revised by ENGR 101 students in the subsequent academic year based on the feedback from the pre-service elementary education students and their faculty instructors. Each new cohort of ENGR 101 students will benefit from using the feedback of ED 401/402 students to redesign and rebuild instructional devices as the basis of learning about the product development cycle. In the end, the improved instructional materials will be given to K-8 schools, and the activities and manuals will be posted on the project web page for dissemination to K-8 teachers, thus meeting one of the goals of the Bridges project to design, build, and deliver instructional devices to support the teaching of science concepts in K-8 schools.

ACKNOWLEDGMENT

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