

The Development and Operation of Adventure Engineering, A K-12 Curriculum Development Program

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Introduction

The need for effective K-12 engineering outreach is apparent. The burgeoning demand for a technical workforce far outpaces the supply currently graduated. According to the National Science Foundation, U.S. colleges awarded 37 percent fewer degrees in computer science, 24 percent fewer in math, 16 percent fewer in engineering and 2 percent fewer in physical sciences in 1998 compared to 1988. Enrollment in engineering schools has also steadily decreased since 1985.¹ Coupled with the well-chronicled math and science deficiencies in primary and secondary school levels,^{2,3} this has prompted numerous entities to develop and funding agencies to finance K-12 engineering outreach programs. The Adventure Engineering program addresses some of the critical issues associated with these trends by encouraging more students to consider technical careers at the time when they are likely to be exploring possible career paths, the 5th through 9th middle grade years.

Adventure Engineering (AE), launched in 1999 with funding from the National Science Foundation, is a middle grade science and math outreach initiative aimed at students who without the benefit of a positive mathematics and/or science applications experience will not consider technical careers in mathematics, science, and engineering. AE strives to (1) improve interest in and attitudes towards mathematics, science and engineering; (2) improve concept learning in science and math; and (3) provide a hands-on, minds-on, meaningful and enjoyable engineering experience. The AE program involves the development and implementation of single day to four-week adventure-driven engineering-based curricula for grade 5 through 9 science and/or math classes. Given a designated time period and concepts identified in national math and science standards, the AE team develops an adventure-based scenario filled with obstacles that require the learning and application of the desired science and/or math concepts. The curricula are inquiry-based and open ended; activities are designed to facilitate concept understanding and immerse students in the engineering design experience. The AE curriculum units are designed to more effectively teach required math and/or science concepts in the same amount of time traditionally devoted to these concepts. Further, the curriculum units are specifically developed for existing middle grade math or science classes to reach all students during the regular school day and to enable adoption in any school without modifications to the infrastructure, e.g., creation of new classes, after school program, etc. This paper chronicles the curriculum development process used by the AE program, focusing on the project participants, effective curriculum characteristics, and lessons

learned. The paper also provides examples of AE curricula and touches on assessment results.

Adventure Based Curriculum

In response to the well-chronicled science and mathematics skill deficiencies in our nations primary and secondary school students, the *National Science Education Standards*² recommended that teachers of science should plan an inquiry-based science program for their students, guide and facilitate learning, engage in ongoing assessment of their teaching and of student learning, and actively participate in the ongoing planning and development of the school science program. The program of study in science for all students should be developmentally appropriate, interesting, relevant to students' lives, should emphasize student understanding through inquiry, and be connected with other school subjects. The *Principles and Standards for School Mathematics*³ advocates similar principles for mathematics teaching and learning. These standards are grounded in the belief that all students should learn important mathematical concepts and processes with understanding. The content in each AE curriculum unit is aligned with the concepts, standards, and principles outlined in the *National Science Education Standards* and the *Principles and Standards for School Mathematics* as well as those concepts already established in the existing middle school classroom's curricular framework as suggested by the State of Oklahoma.⁴ We incorporate engineering methods and principles into each middle grade level by developing design-centered and inquiry-based⁵ mathematics and science lessons. A design-centered approach is supported by most engineering disciplines whereas learning through inquiry is supported by many educational organizations.^{2,3,6}

The AE curriculum units are adventure based and are designed to address specific segments of middle grade math and/or science classes. A summary of four example units are presented as follows:

- *Engineering the Congo*: Student teams design a covert expedition deep into the Congo to extract diamonds from a mountain stream. They are faced with numerous obstacles including water purification, crossing perilous canyons, navigation to the prescribed location, diamond extraction from soil beneath a flowing stream, power generation, and wireless communication. Developed for 8th and 9th grade physical science.
- *Treasure Hunt*: Student explorer teams look for hidden treasure on an island in the Bermuda triangle using global positioning system navigation as well as more precise pacing methods. The curriculum teaches algebra and geometry concepts, involves data collection, and error analysis. Developed for 7th, 8th, and 9th grade math.
- *Surviving the Biosphere*: Students become part of an engineering team that has been locked inside a failing biosphere and must determine the cause of oxygen/carbon dioxide imbalance through data collection, experimentation, and problem solving. Students then must design and implement a solution. Developed for 8th and 9th grade physical science.

- *Asteroid Impact*: Student teams must determine the size and location of underground caverns to save the inhabitants of Oklahoma from an impending asteroid impact and subsequent inhabitable period. Students investigate State geological maps for prominent mineral and rock types, aquifers, earthquake faults, etc., determine required cavern dimensions, and determine rock properties (e.g., hardness, density, luster, etc.) via testing. Student teams then analyze all of their collected data, explore web resources, forge multiple solutions, and narrow to a recommended design. Developed for 7th and 8th grade earth science.

Each curriculum unit includes a teachers guide with step-by-step instructions for each activity. Within the teachers guide, sections provide detailed information including activity overview, purpose, background, principles covered, materials, pre-requisite knowledge, and assessment rubrics. Multimedia modules and Internet resources are embedded within each curriculum unit. The teachers guide provides an easy to follow blueprint that enables teachers to implement each unit with little prior engineering knowledge. While challenging, unassisted teacher implementation is our goal. We want teachers from communities across the U.S. to download and implement AE curriculum from the AE website with little assistance. Activity directions, handouts, and worksheets are incorporated into the teacher's guide for distribution to their students.

Curriculum Development Participants

AE program personnel include faculty from the Colleges of Engineering and Education, graduate students in engineering and education, undergraduates in engineering, and middle grade mathematics and science teachers from urban, suburban and rural school districts in Oklahoma. Curriculum units are developed by subject specific (e.g., earth sciences) curriculum teams. Each AE curriculum development team consists of one to four graduate and undergraduate engineering fellows from various engineering sub-disciplines, one to two graduate education students, and four to six middle grade mathematics and science teachers from the selected subject level. Faculty members from both Colleges provide quality feedback pertinent to their field of expertise. Graduate students in education and middle grade classroom teachers collaborate with engineering students offering pedagogical assistance when necessary. Each curriculum team works together through the design, development, and implementation of their particular AE curriculum. This attracted more adventuresome individuals who are capable of handling high levels of ambiguity.

We had significant success by hiring talented upper division (juniors and seniors) undergraduate students. Talented does not necessarily imply stellar grades; rather, enthusiasm, creativity, a desire to work with kids, and the ability to work in teams are equally and sometimes more important characteristics. Further, we have found that these characteristics are more readily found in undergraduate students than in graduate students. We felt it critical to build a highly diverse team of engineering students to create curricula that makes an impact in the lives of middle grade students who otherwise would not pursue engineering, including female and minority students. We assembled a diverse team by recruiting and hiring an equal number of female and male participants from

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seven different engineering disciplines, and with approximately one half of the engineering participants being minority students.

The teachers involved in the AE program are also quite diverse in terms of gender, background and school setting. Approximately 30 teachers are involved in curriculum development during a given semester. Each of the five AE curriculum teams will involve approximately six subject specific teachers. Diversity in the teachers selected brought multiple perspectives to the project that proved to be invaluable in preparing curricula that will serve a broad spectrum of students and school settings. Although unsuccessful in every case, we tried to place urban, suburban and rural teachers on each curriculum team. Half of the suburban teachers worked in a university community where extensive professional development in inquiry approaches to teaching has been ongoing for over 20 years. The teachers in this district tend to be more familiar with inquiry based instruction although the mathematics teachers in all three settings tended to be unfamiliar with inquiry methods and how they might restructure classroom lessons to reflect this form of learning. Urban teachers tended to be able to talk about inquiry but were in various stages of actually utilizing that type of instruction in their classes.

There has been a great deal of enthusiasm among math and science teachers towards AE. Many of the teachers expressed an interest in having engineering students in their classrooms as role models for their students. We require teacher participants to attend a Saturday morning student/teacher workshop once a month during each semester. In addition, one teacher from each curriculum team spends 2-3 hours each week in the role of teacher mentor helping students craft obstacles that would be standards based, interesting and age appropriate. Participating teachers were provided a \$50.00 stipend for each of the sessions they attended. As the project progressed the value added by having the teacher component to this program became increasingly apparent as students wrestled with the complex task of writing curricula. Teacher mentors were able to facilitate this process. The strength of their commitment to the project was reflected by the fact that, to date, all of the teachers have elected to continue in the program following their first semester of participation.

Curriculum Development Approach

The AE curriculum development process begins with the engineering students within a team observing a selected classroom (e.g., 8th grade math) and interacting with the teacher and middle school students. This orientation period provides the engineering students with an opportunity to build a relationship with the teacher, to observe teaching methods, and to observe student-teacher interaction. Also, the engineering students learn about specific district content requirements, classroom logistics, and class schedules for the semester or academic year.

The engineering students begin to formally brainstorm possible adventure scenarios that will serve as the curriculum theme. Once the storyline for the scenario has been developed, the AE team crafts obstacles and activities that require both the learning of the desired math or science concepts and the application of the desired concepts to solve the problem and/or design a solution. All AE curricula employ an inquiry-based approach to

concept learning. The curriculum is designed to utilize available textbooks and the Internet.

Each engineering student devotes from 10 to 20 hours per week to the development and implementation of curricula by participation in curriculum unit team meetings, visits to teacher classrooms, and AE team seminars and workshops. Numerous two-hour seminars are conducted during each semester expressly for the engineering students. During this time student teams are formed and are guided through the curriculum development elements including such topics as the purpose of education, Piaget's model of mental functioning, the structure of inquiry and how it is reflected in curriculum, lesson plan templates, assessment, national and state mathematics and science standards, web-based curriculum, and questioning techniques. We feel the seminars are invaluable for many reasons. First, effective teams must be constructed through icebreakers and team building activities. Second, effective AE curriculum development relies on creative. This was promoted through creativity and brainstorming activities. We found it to be vital that faculty and program coordinators expedite and shepherd these processes by facilitating these activities during seminar sessions. Third, engineering students (and some faculty) are not versed in inquiry-based middle grade math and science curriculum development principles. Hence, College of Education faculty and graduate students teach these principles and guide students through curricula development using lesson plan templates.

To build synergy among teams and to develop effective curricula, monthly Saturday morning workshops were held to bring together all program participants - teachers, students and faculty. In addition, the students from each curriculum team meets weekly with a teacher from the group. Engineering students have neither taught nor developed curricula and we found the middle grade teachers were unfamiliar with engineering. Creating a product as complex as an adventure-based engineering curriculum for mathematics or science classes required a truly multidisciplinary effort. The engineering students realized very quickly that they had to engage, involve and rely upon the middle grade teachers, the program coordinator and faculty. The teachers relished the curriculum development role and enjoyed working with the engineering students. The fact that students made regular classroom visits over an extended period of time also allowed for both students and teachers to get to know each other and learn to effectively work together.

To further promote teamwork and purpose, the engineering students are given dedicated University space to support their curriculum development effort. Each curriculum development team is given approximately 120 square feet of project space with tables, filing cabinets, Ethernet connection, white boards and wall space to display project ideas in the form of poster size note pads or theme-based bulletin boards. Each team schedules approximately 10 hours of group time each week in their team space. There is also an open area that supports team working.

Once developed, AE students assist the teachers to implement the curriculum. More importantly, the AE students observe and assess curriculum implementation by noting student responses during each activity and the teacher's effectiveness in facilitating each

activity. Since the curriculum is designed for unassisted use, engineering student observations and the subsequent revisions to the curriculum are essential to the curriculum development process. Each curriculum goes through alpha, beta and gamma testing and revisions before being made available to teachers outside the AE program. During this process, rigorous pre- and post-attitudinal and concept assessment is performed to measure the efficacy of the curriculum. The analysis and documentation of curriculum assessment is currently being performed.

Assessment

To determine the level to which the AE curriculum units are meeting program objectives (see Introduction), attitudinal and content knowledge assessment instruments have been developed. The instruments are administered to the middle grade students prior to and immediately following AE curriculum unit implementation, and require written response. Each teacher also provides written and verbal feedback. The assessment instruments and findings from six curriculum unit implementations are described in detail elsewhere⁷ and summarized here.

After each AE curriculum unit, teachers expressed an increased interest and enthusiasm for learning among their students. Assessment data showed that the AE curricula has successfully improved math and science content knowledge, more so than traditional curricula approaches. Assessment also revealed that the AE curricula improved attitudes towards math and science, and in limited cases, attitudes towards engineering. The assessment data has revealed that the AE curricula did not significantly improve student knowledge about engineering. In addition, student perception of being personally successful as an engineer or of engineering being enjoyable increased, but not in a statistically significant fashion. With this assessment data, we are working to improve the engineering components and message of the AE curriculum units.

Summary

The Adventure Engineering program strives to create engineering based curricula for mainstream middle grade math and science classes so all students have the opportunity to experience the exciting, rewarding and enjoyable fields of engineering. Adventure Engineering curriculum units have been developed to effectively improve math and science concept learning, and to provide an enjoyable and meaningful engineering experience for middle grade (5-9) students.

Acknowledgments

Adventure Engineering is supported by grants from the National Science Foundation (Grant Nos. DUE-9950660 and GK-12 0086457). We are extremely grateful for their support. We also acknowledge the effort and contributions of the many engineering students and middle grade teachers who helped develop and implement the AE curriculum.

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