AC 2011-500: USING THE ENGINEERING DESIGN PROCESS TO DEVELOP AND IMPLEMENT A HIGH SCHOOL INTRODUCTION TO ENGINEERING COURSE

Eugene Rutz, University of Cincinnati

Eugene Rutz MS, PE is an Academic Director in the College of Engineering & Applied Science at the University of Cincinnati. He manages the college's dual degree programs and the outreach to local high schools. Mr Rutz has experience as a mechanical design engineer, in nuclear power engineering and as a radiological engineer. He teaches courses for the College using distance learning and instructional technologies.

Using the Engineering Design Process to Develop and Implement a High School Introduction to Engineering Course

Abstract

The University of Cincinnati's College of Engineering & Applied Science in collaboration with local high schools developed an Introduction to Engineering course for high school students using the engineering design process to guide the course development and implementation. The steps in the course design process are described in terms of the engineering design model as are selection of specific course elements. The iterative nature of the process is illustrated and the improvements made after an implementation cycle are described. The course effectiveness is also discussed in terms of meeting the identified goal.

Course Design

In the fall of 2006, the College received several calls from local high schools asking for guidance on providing engineering-related instruction and experiences for their students. A working group was established with representatives from the College and three local high schools (two all girls schools and one school with a significant minority population). Using the engineering design process (see Figure 1) as a model for developing an appropriate solution, the working group first sought to clearly identify the issue and define the problem to be solved. As a matter of primary importance, the collaborators first defined the learning goals for the students[1] – to increase students' understanding of, and enthusiasm for, engineering and engineering technology careers so that more students choose to pursue these types of careers.

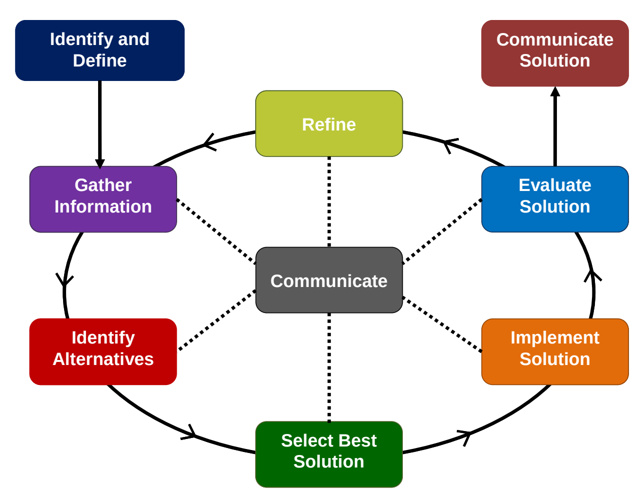

Figure 1 Engineering Design Process

The working group met regularly in order to have a solution in place for the following school year and to facilitate the robust communication required to allow the process to work well.

The collaborators next gathered data both on what was known from the literature regarding accomplishing the learning goals and on existing approaches. Each collaborator sought to identify information on schools that had a similar program and on curriculum that was available to meet the defined goals. Several ideas identified from the literature were of particular relevance: Anderson and Gilbride[2] have demonstrated that a participatory program develops greater interest in women students; Tyson et al.[3] describe the need for better preparation in order to encourage minorities to enter STEM disciplines; Besterfield-Sacre et al.[4] report on the significance of students' attitude toward problem solving and background knowledge to persistence in engineering.

Following the data gathering phase, the collaborators worked to identify alternative approaches to the meet the defined goal. Several existing programs were identified, most notably Project Lead the Way[5], Engineering by Design[6], and Engineering Your Future[7]. Rutz et al.[8, 9] reports on this phase of the course design process. With the identification of a number of alternatives, it became clear that additional data needed to be gathered. In particular, information about the schools (and other schools who might participate later) was needed to better enumerate the constraints faced by the schools. This information was essential in selecting among the alternatives. Particular constraints identified included:

- Limited resources for purchase of curricula or materials – schools had funds to adopt a textbook but no other source of funds for specialized curricula or materials.
- The need to implement the solution with existing teachers – new teachers with engineering credentials would not be hired (related to the limited resources) and significant funds for professional development were not available.
- Significant variations in the type of student who would participate – in some schools the top scholars were the target audience; at another school, the desire was to have the program provide a needed opportunity for students in the middle of the academic ability range.

In addition the College collaborator identified the requirement to develop a scalable solution as a constraint. While there were initially three high school partners, the need identified in the first step of the process affected almost every school. A solution that could be scaled to other interested schools was required.

Considering the existing solutions and the constraints faced in the implementation of any solution, the collaborators concluded that none of the alternatives was able to provide the solution needed while meeting the constraints. However, a number of the alternatives significantly informed the selection of the most appropriate solution.

Using what was learned through the process, the collaborators developed a project-based course that required students to work in teams to solve open-ended problems. Connections to math and science content are reinforced through the projects and concepts learned in these courses are given a context in the physical world. Many of the projects require written reports and presentations in order to further develop students' communication skills. The project based nature of the course provides the essential second step in the backward design process described by Wiggins and McTighe[1] in that demonstration of student understanding for the projects requires students to explain, interpret and apply principles.

To accommodate the needs of the schools, there is not a set syllabus or a required set of projects. A flexible syllabus is followed that provides broad engineering topics (engineering design, teamwork, and communication) and specific engineering disciplines. Schools are not required to spend a set amount of time on any topic but have the flexibility to devote the time appropriate for their particular setting.

Similarly, there are no required projects. For each topic and discipline, several different projects were made available. Participating schools choose a project that fits their student population, resources and interests. For example, in the unit on Civil Engineering, some schools used a balsa wood bridge project, others a pasta bridge project, and others a straw tower project.

Since existing high school instructors (who likely have no engineering background) would lead the course, the in-class projects are scaffolded with instruction provided by instructors from the University. With the intent to develop the content to be affordable, accessible and scalable, instructional modules were created using web 2.0 tools. Presentations were captured and presented via a web page as streaming media. This allows the students and teachers to access the content according to their schedules and supports large numbers of users without requiring additional time on the part of University faculty.

A textbook, Engineering Your Future[7] was selected to support the course. The text is used to provide instruction that complements the web-based modules. The text also provides a number of excellent projects that can be completed in the classroom. Additional projects were collected and provided from other peer reviewed sources.[10-12]

The course was structured to provide the high school students a similar experience that University students have who participate in the course Engineering Concepts, a course offered for college students who are undecided about the major they will pursue. The college course provides an introduction to the engineering disciplines offered in the college, facilitates interactions between the new students, faculty and current students and introduces new students to the practice of engineering.

Course Implementation

The course was implemented in the 2007 – 2008 school year at four high schools in the Cincinnati region. The course was offered as an elective for students and typically counts as a science credit. In the summer prior to the start of the school year, the College sponsored a professional development workshop to provide instructors a foundation for teaching in a project-based environment. Teachers learned the engineering design process and then experienced the process as they participated in project work. The teachers were also given instruction on how to access and use the web-based instructional materials.

A typical unit of instruction begins with an introduction to that topic by the high school instructor. If appropriate, readings from the text are assigned and students are required to watch the instructional video module(s) associated with the unit. The project is then introduced and the correlation between the project and the engineering topic discussed. Projects are conducted in class, typically in teams, over several class periods. In addition to the artifact produced through the project, some projects require a written report and / or an oral presentation by the team.

The high schools arrange with working engineers and / or University faculty to visit the classroom and share their experiences with students. Schools also make arrangements with local engineering firms to visit the organization and allow students greater interaction with working professionals.

The University provided free access to its Blackboard course management site for all participating students and teachers. The Blackboard site hosted teaching resources, instructional resources, and links to all the instructional modules. During the school year, the instructors and University project manager continued to meet to provide purposeful and regular opportunities for communication.

Evaluating and Refining the Course

In the initial year of implementation 80 students participated in the program. On a pre-course survey 26% of students indicated they were very interested in studying STEM disciplines in college while on the post-course survey, 58% of students indicated they were very interested in studying STEM disciplines in college. Common themes that students expressed regarding their experience in the course included:

- Students learned physics and how to use physics to solve problems
- Students were able to describe the variety of engineering disciplines
- Students developed an understanding of the significance of teamwork
- Students developed skills in solving problems

In focus group discussions with both teachers and students, the following points were made:

1. Leading a project-based course was a tremendous amount of work the first year, but well worth it. All teachers expressed a strong desire to continue this approach.

2. Students are initially frustrated by the open-ended nature of many of the projects. In particular, academically high achieving students are used to solving problems with one correct answer. When multiple solutions exist, and when a teacher can not confirm that a student has the one correct answer, this is disconcerting to students.

3. Availability of the instructional modules was a valued resource, however students indicated that a number of the videos were too long to hold their attention.

4. Using the course management system to host the content was useful but not ideal. The structure allows for ease of use but is not appealing or conducive to spending time on the site. The need to have usernames and passwords was cumbersome.

5. The meetings with teachers were very valuable. Teachers shared experiences on projects and in classroom management. This also provided a forum to identify what worked well and what did not.

Lessons learned during the initial implementation were used to modify the program. In particular, several video modules were redone to make them shorter. Most modules are now between 10 – 15 minutes in length. The content was migrated from the course management system to an open wiki site at http://sites.google.com/site/eyfcincinnati. The wiki site also has the added advantage that high school instructors can contribute to the site with lesson plans, grading rubrics, and project plans. A discussion forum is also available that facilitates continued discussion among teachers.

Changes were not made to the open-ended nature of the projects. While some are challenging to lead and can cause students to struggle, they represent the best opportunity for students to experience the true nature of engineering. Moreover, once students succeed in the project work, their sense of accomplishment and enthusiasm for learning increases significantly.

Continuing the Process

Since the initial implementation, the course has continued to grow in number of schools and students participating as shown in Table 1.

Table 1 Course Enrollment

	Schools	Students
2007	4	80
2008	5	106
2009	8	249
2010	11	364

Data gathering to inform the efficacy of the design and the implementation is ongoing. There have been no funds to provide a rigorous, external evaluation of the program but the collaborators have collected student data and a number of teacher focus groups have been held during the life of the project. Recognizing that this course engages students through many non-traditional means, the collaborators sought to identify the significance of different aspects of students' experiences. Many educators conclude that social interactions and observations of peers and experts mediate knowledge and behavior.[13] Whether one subscribes to a social cognition theory of learning or not, the context of learning for most students is in the framework of a classroom of peers such that interactions with other learners is inseparable from the learning experience.

As a measure of how classroom time and the overall course experience should be constructed, we sought to identify the significance of 1) instruction, 2) activities (project-based learning), and 3) interactions in student learning. A survey was constructed and administered to the course participants prior to the course to develop a quantitative understanding of the perceived significance to the students of instruction, activities and interactions. In addition a focus group discussion was conducted with the teachers to identify their perceptions of the importance of these three items.

Three hundred and sixteen students from nine schools completed the pre-course survey at the beginning of the school year. Two schools who completed a semester long version of the course have taken a post-course survey (total of 27 students). The remainder of the schools will not complete a post-course survey until late May or early June. An analysis of differences pre- to post-course is not meaningful until all data is collected.

<u>Student Responses – Pre-Course Survey</u>

Figures 2 and 3 illustrate student responses to college and career interests regarding STEM.

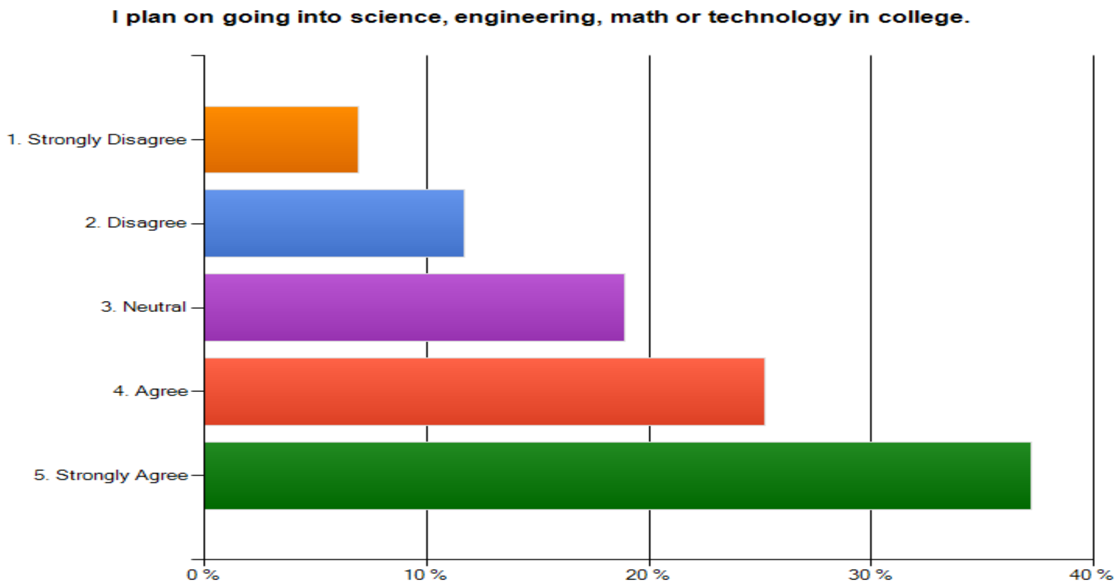

Figure 2 Student Interest on Studying STEM Disciplines in College

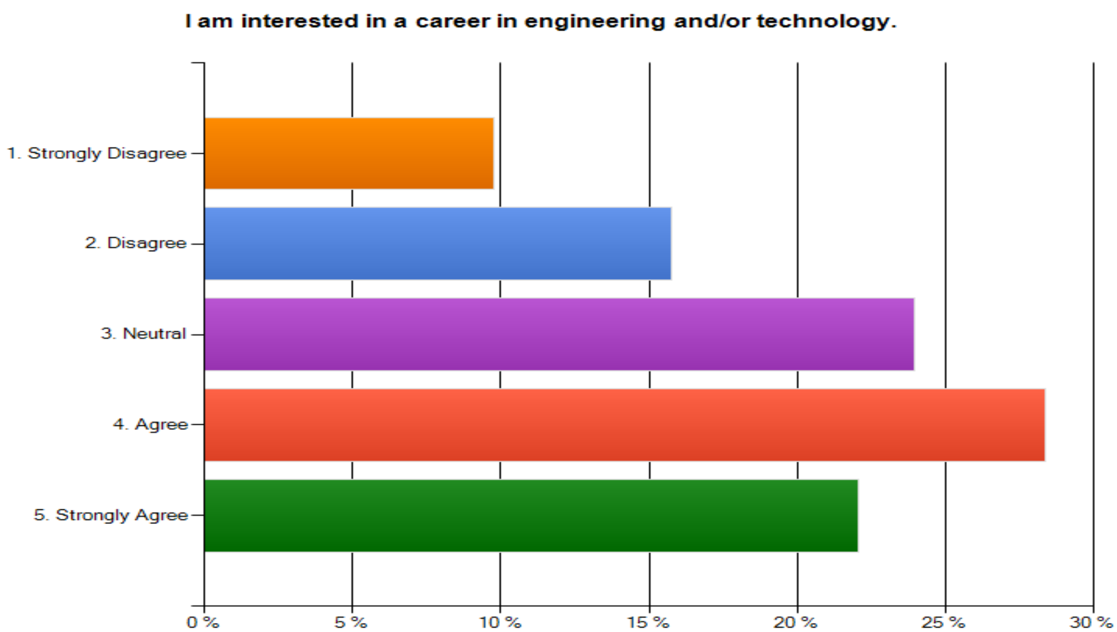

Figure 3 Student Interest in Engineering & Technology Careers

Figures 4 – 6 illustrate the perceived significance of instruction, activities, and interactions in learning.

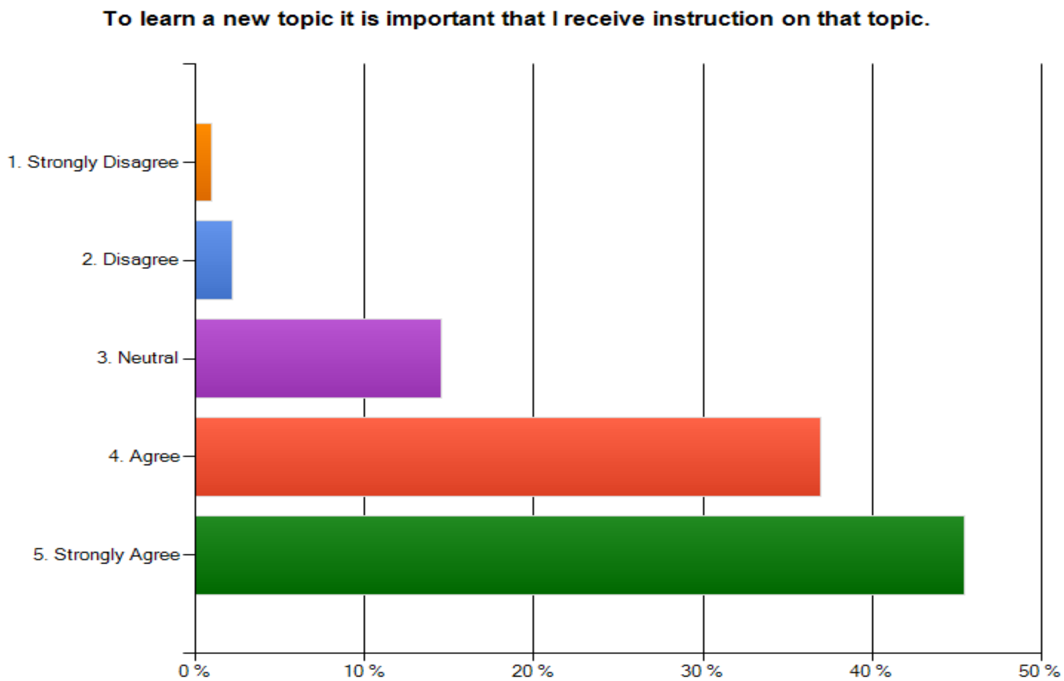

Figure 4 Significance of Instruction

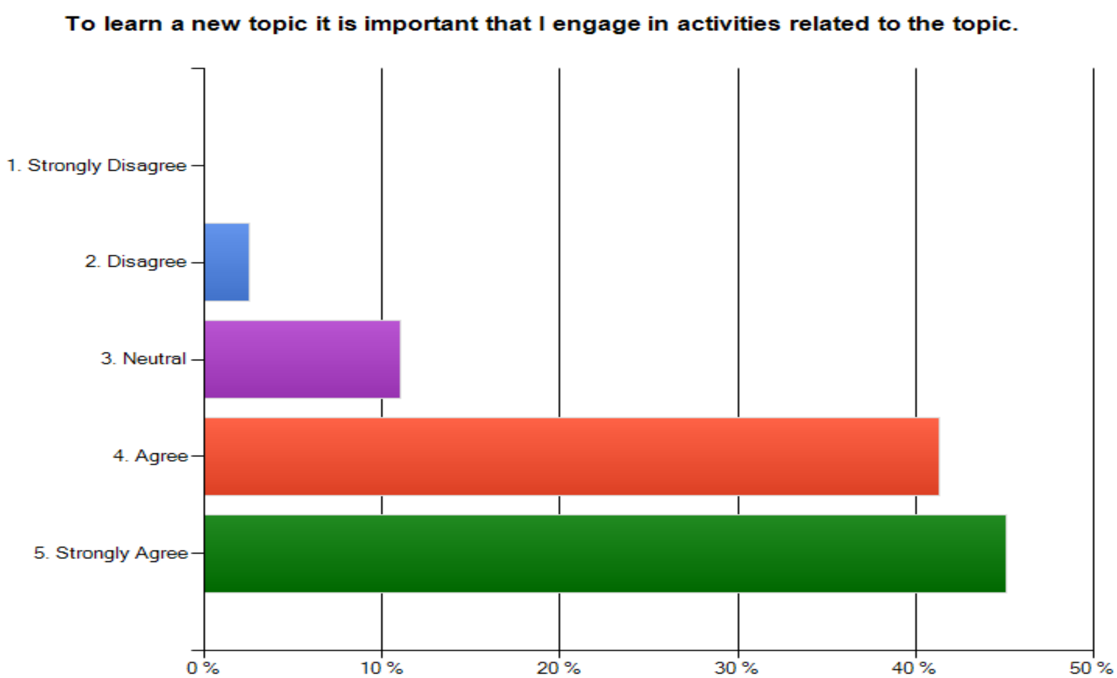

Figure 5 Significance of Activities

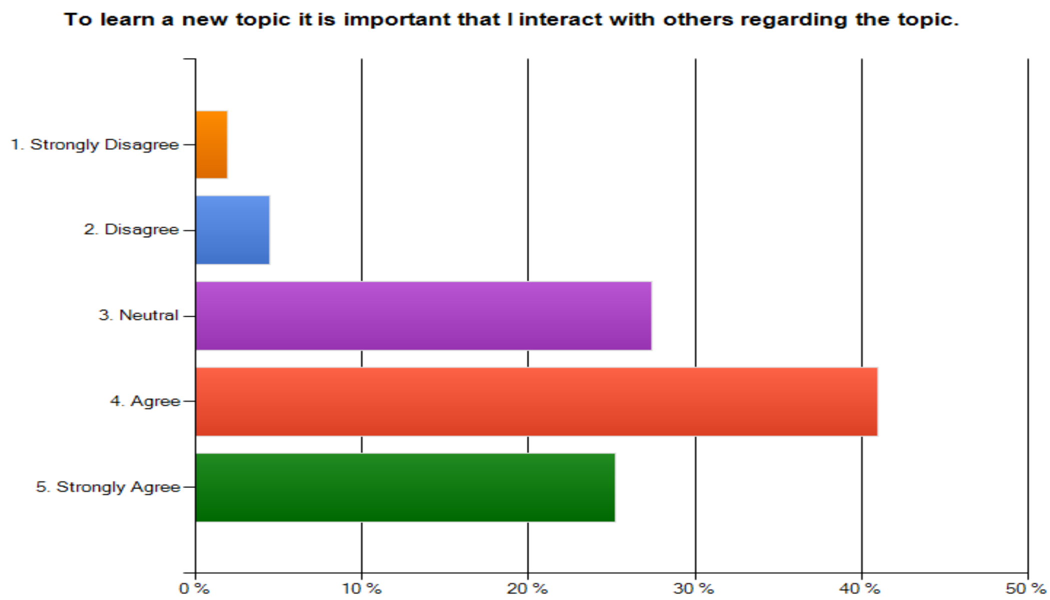

Figure 6 Significance of Interactions

Students in the course were surveyed at the end of the third quarter of instruction about their college plans. Of the 76 students responding, 53% indicate they plan on enrolling in engineering in college. Of those students planning on enrolling in engineering 75% indicated that participation in the course was a significant factor in that decision.

<u>Teacher Responses to Focus Group Discussions</u>

It is quite clear from discussions with the teachers that this course is much different than most (if not all) courses that the high school students experience. The project-based nature of the course that requires students to work together to solve open-ended problems provides a learning environment that challenges and rewards learners.

Regarding *instruction*, the teachers comment:

- Through this course the teacher is seen as more of a resource than an expert. There are times when, rather than knowledge on a topic, students simply need the confidence to proceed with the project. Teachers can help instill this confidence.

- Students can rush past instruction to begin a new project. After working on the activity for a time, they realize they need knowledge and information and come back to the teacher (or text or video) for the instruction.

- Students are forced to learn from each other as well as the instructor. They ask each other how they accomplished a particular task or solved a particular problem and help each other get the work completed.

Regarding *activities*, the teachers comment:

- Students absolutely learn the topic best by actively working on the projects.

- The activities provide an opportunity to synthesize topics from other courses. This does not happen in traditional high school courses and is a very valuable outcome.

- The activities and applications enable students to see and experience the value of learning mathematics.

- They are challenged by the activities. They struggle with not getting a correct answer. When they finally understand that it is ok to fail and they can try again (or that failure does not affect their grade significantly) students are more willing to try more interesting solutions to the challenge.

Regarding *interactions*, the teachers comment:

- In many instances the students learn best from each other. Working on the activities together, discussing ideas with peers, and discovering potential solutions excites the students. This sentiment was particularly prevalent among teachers at the all-girls schools.

- The open-ended nature of the projects often means the instructors and students are learning along side each other. This provides a significant opportunity for the instructor to model a problem solving process, allows a different form of teacher-student interaction than normally present in high schools, and builds confidence in students.

- This course of study is all about the interactions between the students. Partners learn they must tell each other what they are doing and where they need help. When they are absent, they need to tell the others in the group where their work is so they can get to it.

Another significant observation was that the course provides an opportunity for students to take risks; something they do not get in other courses. Students come to understand that not all project designs are successful; there are times their solution fails. This is difficult for students to accept, particularly high achieving students who are accustomed to doing well in traditional courses. With proper application of the design process though, students learn from their mistakes and what they learn appears to "stay with them" in a more significant way than what they learn from a lecture based course.

The need for taking risks and the reality of failure is reinforced by working professionals who visit the classroom and share their experiences. The value of this process and the importance of learning from failures are made clear to students.

Discussion Regarding Recent Data Collection

The survey was administered at the beginning of the school year prior to the course so it should reflect students' self-analysis based on their previous experiences in their school setting. Reviewing Figures 4 – 6, approximately 82% of students indicate instruction is either significant or very significant; 87% indicate activities are significant or very significant and 66% indicate interactions are significant or very significant. This is a more balanced perspective than was expected and clearly indicates students' preference for active learning settings. It is also interesting to note the small number of students who were neutral regarding the significance of instruction and activities while a greater number were neutral regarding interactions. When only students at the all-girls schools were included (126 students) 89% indicate instruction is significant, 90% indicate activities are significant, and 71% indicate interactions are significant.

Teacher responses were gathered at the conclusion of the first semester of the current school year. With a few exceptions, responses from teachers were consistent regardless of the school and characteristics of the student body. All continue to report that the open-ended nature of many of the projects was a challenge to students and often presented the greatest challenge to academically high-achieving students. These students have learned through their schooling that a good student can identify the correct answer and there is typically only one correct answer. Problems and projects for which multiple solutions exist are a challenge to their understanding of education. Confronting this challenge and enabling students to experience characteristics of the work world provides a more robust understanding of what is needed to contribute and be successful in engineering.

A related issue reported by teachers is that students do not know how to handle failure on a project. The academic setting has instilled the idea that failure of any sort is unacceptable. The projects and the interactions with working professionals present another picture that failure will occur and provides a significant opportunity for further learning and improvement. Developing skills to learn from failure is important and these skills are lacking in typical courses.

The teachers also describe the enthusiasm among students when a team of peers is working well together on a project or to solve a problem. Team members provide instruction, feedback, encouragement, and critique without intervention from the teacher. The teachers describe this as the best environment for learning.

Further Refinement

To have a greater impact on students at the participating schools it would be advantageous if these students took the course prior to the senior year. That placement would provide greater time for high school students to explore college options and to take additional course work that prepares them to be successful in the study of engineering in college. A number of the high schools are promoting the course for juniors and in some cases sophomores.

Middle school students would benefit substantially from an opportunity to participate in a project-based course that introduced the engineering design process and the practice of engineering. Students who developed an interest in engineering (and other STEM disciplines) could then receive academic counseling to pursue appropriate high school course work. The pedagogical model and implementation framework of the existing high school course is being used as a model to develop modules of instruction for middle school students.

Conclusions

Based on the value the participating schools place on the course, the collaborators have met the intended goals of enabling greater numbers of students to make informed choices about pursuing engineering in college and the workplace with a program that was affordable, adaptable, and scalable. Since funds for a robust evaluation have not been available, we have not been able to evaluate if the new program meets this goal better than other programs or other traditional high school courses. However, based on the behavior of schools we conclude that the new program is valued since more schools and students continue to adopt the program with no marketing of the program by the university.

Open-ended projects that facilitate the activities and interactions help students develop a realistic attitude toward engineering careers and an appreciation for the value of teamwork. These projects provide valuable skill development in applying the engineering design process, encourage creativity and provide a mechanism for students to learn from failure. The project based nature of the course also facilitates learning through instruction, activities and interactions.

Finally, an introduction to engineering course in high school can be an effective means to encourage more students to pursue engineering in college and the workforce.

References

1. Wiggins,G., McTighe, J. 2001. Understanding by Design. Prentice Hall.

2. Anderson, L. and K. Gilbride. 2007. The Future of Engineering: A Study of the Gender Bias. *McGill Journal of Education.* Vol. 42, No. 1, pgs. 103-117.

3. Besterfield-Sacre, M., M. Moreno, L. Shuman, and C. Atman. 2001. Gender and Ethnicity Differences in Freshman Engineering Student Attitudes: A Cross-Institutional Study. *Journal of Engineering Education*. Vol. 90, No. 4, pgs 447-490.

4. Tyson, W,. L. Geginald, K. Borman, and M. Hanson. 2007. Science, Technology, Engineering and Mathematics (STEM) Pathways: High School Science and Math Coursework and Postsecondary Degree Attainment. *Journal of Education for Students Placed at Risk*. Vol. 12, No. 3, pgs. 243-270.

5. Project Lead the Way. 2011. Available at http://www.pltw.org/about-us/who-we-are

6. Engineering by Design. 2011. Available at http://www.iteaconnect.org/EbD/ebd.htm

7. Gomez, A., Oakes, W., and Leone, L. 2006. Engineering Your Future: A Project-Based Introduction to Engineering. Great Lakes Press. Wildwood, MO.

8. Rutz, E, B. Lein, M. Shafer, and S. Brickner 2008. Accessible STEM Education. Proceedings of the ASEE Annual Meeting, June 2008, Pittsburgh, PA

9. Rutz, E, B. Lein, M. Shafer, and C. Rost 2008. From 0 to 60 in 1 Year. Proceedings of the ASEE Annual Meeting, June 2008, Pittsburgh, PA

10. Teach Engineering. 2011. Available at www.teachengineering.org. Hosted by he National Science Digital Library.

11. Project STEP. 2011. Activities and Lessons available at http://www.eng.uc.edu/step/. The University of Cincinnati. Cincinnati, OH.

12. Try Engineering. 2011. Lesson Plans available at www.tryengineering.org/lesson.php

13. Bandura, A. 1986. Social Foundations of Thought and Action. Englewood Cliffs, NJ: Prentice-Hall.