AC 2007-151: INSIDE THE CLASSROOM: CHALLENGES TO TEACHING ENGINEERING DESIGN IN HIGH SCHOOL

Sibel Uysal, Arizona State University

Sibel Uysal is a Ph.D. student in Science Education, Department of Curriculum and Instruction at ASU. She earned her MA degree in Science Education at University of Missouri Columbia. Her BS degree is in Biology. Her principle research areas are inquiry-based learning and science and the equity in science education. She works on the project about investigating the efficiency of different type of induction programs on the development of beginning science teachers.

Senay Yasar, Arizona State University

Senay Yasar is a Ph.D. student in Science Education, Department of Curriculum and Instruction at Arizona State University. She earned her MA degree in Science Education at Arizona State University. Her BS degree is in Physics Education. Her principle research areas are inquiry-based learning and science and engineering education. She teaches an elementary science methods course for undergraduate students and is a research assistant on an NSF project.

Dale Baker, Arizona State University

Dale R. Baker is a Professor of Science Education in the Department of Curriculum and Instruction at Arizona State University and was the Co-Editor of The Journal of Research in Science Teaching. She teaches courses in science curricula, teaching and learning, and assessment courses with an emphasis on constructivist theory and issues of equity. Her research focuses on issues of gender, science, and science teaching. She has won two awards for her research in these areas. She was elected a fellow of the American Association for the Advancement of Science in 2004.

Sharon Kurpius-Robinson, Arizona State University

Sharon E. Kurpius Robinson is a professor of Counseling Psychology. She has received numerous national grants examining undergraduates' academic persistence and the academic success of talented adolescent girls. She was recently named a "Multicultural Scholar" by the NACAC for her work on the retention of racial/ethnic minority students in higher education.

Stephen Krause, Arizona State University

STEPHEN J. KRAUSE is Professor and Associate Chair of the Chemical and Materials Engineering Department. He teaches courses in general materials engineering, polymer science, characterization of materials, and materials selection and design. He conducts research in innovative education in engineering, including a Materials Concept Inventory, and also in adapting design, engineering and technology concepts to K-12 education. He is currently working on an NSF sponsored MSP developing courses for high school teachers connecting math, science and engineering.

Chell Roberts, Arizona State University

Chell A. Roberts is an associate professor and Director of Engineering at Arizona State University Polytechnic. He received his Ph.D. in Industrial Engineering and Operations Research from Virginia Tech in 1991. He has a MS in Industrial Engineering and a BA in Mathematics from the University of Utah. He is a member of the board of directors for the Society for Computer Simulation International and has been actively involved in developing undergraduate engineering design curriculum.

Inside the Classroom: Challenges to Teaching Engineering Design in High School

Abstract

The advances in engineering, particularly over the past few decades, have transformed the daily lives of people. This, in turn, has captured the attention of students at all grade levels. The fascination with technology has generated increased interest among students at an early age, and motivated some to study the field of engineering. It is not too early to start building the foundation for engineering education at the high school level where curricula are being modified to increase students' familiarity with engineering. The objectives of this research were to evaluate the experiences of a high school teacher who developed an innovative engineering program and also to prepare a rubric to guide future teachers who want to teach engineering in their classrooms. An introductory engineering course was offered as an elective and taught by a mathematics teacher who was also an engineer with prior industry experience. It was composed of two one-semester components with hands-on design activities. Eighty-six male and four female students in grades 9, 10, 11, and 12 participated. The data was collected through observations and videotapes of the classes. NVivo qualitative research analysis software was used to code the observation notes and to reveal patterns in the data. At the end of this research project, even though the instructor had limited resources, he was able to meet many of the challenges that he faced in creating and implementing the new engineering program. However he did not sustain the students' interest with several hands-on design activities, such as building an airplane, a tower, a bridge, guest speakers, field trips, readings about the design process, and team presentations, Mr. Q. was not able to pay enough attention to some aspects of the class which inhibited the success of the program. For example, the video presentations or activities were selected to reflect the interests of the students, as indicated by student questions or discussions. Gender and minority interests were not explicitly taken into consideration. For example, most videos focused on disasters resulting from engineering mishaps videos that might show the relevance of engineering to society. Furthermore, difficulties were encountered because of grade level differences in maturity, or mathematics and science backgrounds. This was because criteria and pre-requisites were not established for activities, and did not provide enough explanation about the roles of group members.

Introduction

Modern day engineering has facilitated the expansion of student interests in many and varied ways. Because technology is continuously evolving, a new generation of students has been intrigued and captivated by the ever-changing technologies that have introduced computers, instant messaging, information acquisition, information sharing, and web-based computer games –to mention only a few practical implementations of modern technology. All these developments show that engineering education is important for students and such an educational program would support an informed citizenry, meet the needs of an expanding, yet highly specialized workforce, and lead to responsible innovations for the world we live in. Engineering education should be an integral part of the overall educational program offered to students in K-12 for a variety of reasons. First, technology is changing rapidly and this requires that students become more knowledgeable about it. Second, there is a need for a significant increase in the number of students pursuing engineering degrees as a career path. The latest research demonstrates that engineering education, if started in the K-12 classrooms, would have a significant impact on the engineering profession[1], especially because it encourages secondary students to consider technical careers. Although some may argue that it would be better to emphasize the fundamentals of math and science as college preparation for engineering rather than teaching engineering. There are counter arguments about career awareness and that both objectives can be addressed by making sure that fundamental math and science is connected to the engineering course. Engineering courses show how the subjects of mathematics and science are fundamentally helpful for students because they show the connection between the real world situations and science and mathematics. Unfortunately, few schools offer stand-alone engineering courses at any grade level, and most school districts pay little or no attention to engineering education. In addition, there are few teachers qualified to teach engineering concepts and principles because of their lack of an engineering background.

There are a limited number of studies that address the issue of engineering education in high school. Paradoxically, in *Educating the Engineer of 2020,* it is stated that introducing engineering into the classroom at an early age takes advantage of the pupils' early interests and promotes choosing engineering as a future career[1]. In reality, only a limited number of pre-college schools bring engineering into the classroom. This could explain why there are such a limited number of studies in the research literature on the effect of engineering in K-12 education[2]. This is in spite of the fact that there are three national documents that recognize the importance of teaching and learning about engineering principles in K-12 schools: *Benchmarks for Science Literacy*[3]; the National Science Education Standards[4] and *Standards for Technological Literacy*[5]. These documents provide a framework and describe the critical aspects of engineering. Having benchmarks to guide the creation of instructional activities is necessary but not sufficient. There are barriers in implementing engineering education in schools. The main obstacles are teachers' knowledge, or lack thereof, about engineering design and the absence of commonly known teaching methods in the area of engineering education. Even very experienced teachers have difficulty in implementing teaching of engineering design during their first year[6]. The challenge now, according to the American Society for Engineering Education, is to be able to find qualified engineering teachers. Some schools ask science teachers to teach engineering while others hire engineers who have never taught before and yet others retrain former teachers.

Purpose

The purpose of this research study is to investigate the following question: "What challenges do teachers face and affordances they get when implementing a high school engineering curriculum for the first time?" The data was collected to support the development of a high school engineering magnet program as part of a university and high school collaborative program. This magnet program focused on the impact of the high school courses which were intended to teach engineering principles to help students better understand the design process. We were also interested in creating a rubric to help future teachers who want to introduce engineering to their students as part of their educational curriculum.

Theoretical Background of this Research

Socio-constructivist theory provided the framework for this research. Sociocultural theory originated in the work of Vygotsky and his Soviet colleagues in the early decades of the twentieth century. Vygotsky's ideas influenced a social constructivist approach to education. Sociocultural theory is the use of cultural tools (both material and psychological) in the development of understanding. Instruction could be sufficient when students connect with the activities within a supportive learning environment and get appropriate guidance that is mediated by tools. An important aspect of tools is that they do more than simply assist in the development of mental processes. Teachers teach children how to use tools, and children adapt these tools to master their own behavior, gain independence, and reach a higher developmental level. The construction of knowledge and practice occurs as the teacher interacts with the students and the environment while planning and enacting lessons. Within a sociocultural perspective, students who share their reasoning about ideas with others and listen to others share their thinking, thus creating an understanding of their established cultural practices. In 1994, Vygotsky wrote that communication is a cultural tool. He said that language is a cultural tool, a human instrument of communication[7]. For Vygotsky, individuals come to learn the meanings of a culture by internalizing the meanings and are transformed by them as they learn to speak the language of the culture. Thus, students create their own knowledge and develop their learning meaningfully as they learn to explain and justify their thinking to others[7]. Hiebert et al. claimed that a key component of developing relational understanding is communication. "Communication involves talking, listening, writing; demonstrating, watching... participating in social interaction, sharing thoughts with others, and listening to others share their ideas"[8]. When we were observing classrooms, we focused on the communication and the interaction between students and students, and between the teacher and students. From this perspective, it is important to assess the strategies used by the teacher when teaching the magnet engineering program.

Method

Teacher - This engineering magnet program was offered as an elective course and taught by the mathematics teacher (Mr. Q.) who was an engineer with industry experience. One science education professor, one educational psychology professor, two engineering professors and two science education graduate students collaborated with him to broaden the school curriculum to directly address engineering. The teacher went through a post baccalaureate certification program, which provided limited classroom experiences. He decided on a career switch in order to spend more time with his family and to interact with people more. Prior to developing the magnet program, he taught mathematics.

Students **-** Eighty-six male and four female students in grades 9, 10, 11, and 12 participated in this study. The school was located in a high socio-economic area of the state. The district draws from a more diverse socio-economic spectrum but, on the whole, students are well off and both the parents and the district expect their students to be high achievers. Unfortunately, only four female students participated in this program. All of the female students attended a summer workshop related to the introduction of engineering at Arizona State University before this course was offered in their high school. The students were planning to be engineers in their future careers, and would decide which engineering discipline would be most suitable for their interests with the help of participating in the course. Students were recruited throughout the district the spring before the course was offered. The requirements of the courses were different depending on the grade level in this district. Unfortunately, the recruitment did not pay attention to female students' interests and it was given in a very short time. For this reason, female students did not find time to talk each other about the class.

In general, students at the ninth grade level had taken the fewest mathematics and science courses (pre-algebra and general science) and students at the twelfth grade level had taken the most mathematics (geometry, algebra I and II, calculus for university-bound students) and science courses (biology, chemistry, and physics for university-bound students).

Course - The course had two one-semester components with hands-on design activities. The goal of this course was to expose high school students to a broad range of ideas and principles common to engineering. It provided an opportunity for students interested in an engineering career to study and learn about engineering prior to college. The course included a full complement of math and was supported by a comprehensive English, social studies, and science curriculum. Students studied a variety of engineering topics including technology, computer applications, technical communications, and societal concerns, as well other engineering topics.

Moreover, this course was planned for teaching the design process. The design process was read about from a textbook and the teacher discussed what they learned about the process during the class. Learning about design was supported by the hands-on projects, Excel spreadsheet activities, guest speakers, field trips, readings, and team presentations. In addition, this course provided an introduction to five engineering disciplines and the engineering profession in general. Students worked in teams and they designed such things as a bridge, an airplane, and a building. All students who wanted to take the class were so allowed because the principal was concerned that there would not be enough students to fill a class, but instead exactly the opposite phenomenon happened. Also, Mr. Q. told us that the guidance counselor thought that, since it was a hands-on class, it would be good for special education students and others who needed an elective.

The selection of the activities, videos, materials, and the preparation of the curriculum was the responsibility to Mr. Q. and approval from the curriculum committee was not needed because it was an experimental course. The principal approved the course activities and syllabus.

During the year, Mr. Q chose and used three different books as resources which were selected in consultation with ASU engineering professors. They were *Tools and Tactics of Design*, Dominick et al., John Wiley and Sons, 2001, *Engineering Your Future*, Oakes et al., Great Lakes Press, 2003 and *Introduction to Excel, 2^{nd} Ed.*, Kuncicky, D.C, Prentice Hall, 2001.

Mr. Q. used two different types of assessments for evaluating his students' progress in this class. Midterm and final exams included multiple choice, short answer and fill in the blank questions and was used as a summative assessment. The students' group projects such as the bridge, tower, plane, and Power Point presentations were used as formative assessments. He did not use a rubric for assessing the students' projects.

Data Collection and Analysis Method

The qualitative method was used during the data analysis process. The qualitative method accepts the complex and dynamic quality of the social world. The qualitative research includes an *emic* (insider) perspective in contrast to the quantitative studies' *etic* (outsider) perspective. Qualitative research contributes to the field of education by capturing peoples' perspectives, interpretations, and understanding of the discourses that shape social life in schools and society[10]. The data for this study consisted of field notes of the researchers' observations of the classroom activities. Observations continued for two semesters once a week. Observation was the main data collection strategy that was used in this research because observation data allows for a holistic interpretation of the phenomena[11]. Specifically, structured, non-participant observations were used to get the desired in-depth information about the students' interactions, the teacher's instructional strategies, the nature of guest presentations and the other types of activities that were part of the courses. The researchers observed the students and the teacher without interacting with them, and used emergent themes in the data for selecting and recording the data.

Video recording was the second data collection method because of its capability of documenting both audible and visual information in a rather detailed manner. Moreover, the data was thought to be quite accessible because it was easy to view the tapes repeatedly[12]. Generally, there were 10 teams, which included two or three students per team, working at the same time. We wanted to capture as many members of teams interacting as possible. We focused on two teams via the video to make more sense of the data, especially during the hands-on activities.

The data consisted of 15 observations and 10 videotapes. Two observers were present for each observation to increase the reliability of the data collection and to insure agreement on analysis of data. After the each observation and videotape, each researcher wrote what they observed during the classroom and then they compared their notes with each other to increase the reliability.

The NVivo qualitative research analysis software was used to code observation notes and video scenes to reveal patterns in the data. NVivo is a practical teaching tool because it can store many different kinds of documents in one place. All documents are connected together for easy access. In addition, NVivo systematizes raw data (interviews, observations, etc.) and links them with memos and "databites" where researchers can make codes and then edit and rework ideas as the project progresses. It is helpful to keep track of activities from one session to the next. Video images can also be linked to text documents. NVivo has its own language that users need to learn it in order to navigate around the program. For example, a researcher maneuvers from one document to another using this feature. The author creates "nodes" to mark relevant concepts and topics in text documents that can be searched and analyzed. It is a straightforward program to learn, especially for those who are already familiar with a variety of the Windows-based programs[12].

Results and Discussion

There were six fundamental class features observed and videotaped during the teaching process. These included: 1) the role of females in engineering; 2) a presentation of how engineering affects society, 3) teaching the iterative design process and design problem solving, 4) the application and use of modeling tools such as calculus and Excel spreadsheets in engineering, 5) configuration of teams and 6) career information. Using these findings, a classroom observation instrument was developed. Each item of the rubric was related to Sociocultural Theory. The interaction of the students with on another, with the guest speakers and with the teacher helped identify these class features.

Development of a Rubric

Themes emerged from the data that had been collected that were used to develop the rubric. Based on our observations and the videotapes of the high school teacher's lectures, discussions and activities to infuse engineering in his classroom, we developed the rubric outline shown in Table 1. We also analyzed the observations of Mr. Q. An example of applying the rubric for each finding is provided. Using the rubric in this way has the potential to be a good tool for future researchers and as well as for the teachers who want to develop, teach and evaluate a high school engineering course.

Representation of female role models in science
The intent of this category was to determine whether the teacher was aware of issues related to women's participation in engineering and whether these issues were being examined critically from multiple perspectives.

Representation of how engineering affects society
The intent of this category was used to determine whether the teacher could positively explain the role of engineering in everyday life.

Teaching the iterative design process and design problem solving
The intent of this category was used to determine if the teacher could explain the design process, including steps on problem scoping, consideration of alternative designs, construction, testing, modifications, and communication. In addition, this category included whether the teacher could integrate clearly each step of the interactive design process into the classroom activities.

Application and use of modeling tools such as calculus and spreadsheets in engineering
The intent of this category was to determine how the teacher used calculus and the spreadsheet to teach the design process and how effectively he integrated them in order to meet the needs of students that were from different grade levels or were participating in different activities.

Configuration of teams
The intent of this category was to determine whether the teacher considered the different team configurations and whether the teacher changed the team configuration to increase their success in applying the design process and problem solving.

Career information
The intent of this category was to determine how well the teacher represented different branches of engineering and if he encouraged the students to research what possible kinds of engineering fit their interests. In this part, we explained our research findings under each rubric's categories.

Table 1: Rubric of observation & video notes

Category	Items	*3*	*2*	*1*	*0*
ROLE MODELS -- DIVERSITY	**1. Representation of gender in the instruction, videos and by the guest speakers.**	*There was an equal representation of males and females in the videos. There were female guest speakers. Females were encouraged.*	*There was an equal representation of males and females in the videos or there were female guest speakers*	*There was not an equal representation of males and female but the issue is discussed*	*All of the engineers presented in the videos were male*
	2. Representation of collaboration through hands-on activities	*The activities were non-competitive and the emphasis was on iteration and improvement*	*The activities were somewhat competitive but the grading or recognition was based on a criterion-based assessment*	*The activities were competitive but students were not graded with a norm-based assessment*	*The activities were competitive and students were graded in a norm-based assessment*
SOCIAL RELEVANCE / POSITIVE IMPACT	**3. Representation of positive impact of engineering**	*Activities showed how engineering and technology better people's lives*	*Activities showed both the positive and negative impact of engineering and technology*	*Activities showed mostly the negative impact of engineering*	*The activities were focused on engineering disasters*
ITERATIVE DESIGN PROCESS & PROBLEM SOLVING	**4. Process vs. Crafts approach**	*Activities emphasized the iterative design approach with an emphasis on the process*	*Activities emphasized the design approach but were not iterative*	*Activities partially emphasized the design approach*	*Activities emphasized a crafts approach and did not address the design process*
USE OF MODELING TOOLS & METHODS	**5. Embedded Models**	*Modeling was embedded in the design problem solution process and students understood the rationale in using the model*	*Modeling was embedded in the design problem solution process without consideration of students' understanding*	*Modeling was not embedded*	*Modeling was not considered*
	6. Assessment of students' cognitive levels and background knowledge	*Students' prior knowledge and skills were assessed to provide scaffolding*	*Students' prior knowledge was not assessed but some scaffolding was provided*	*Students' prior knowledge and skills were assessed but this information was not used to provide scaffolding*	*Students' prior knowledge and skills were not assessed*
TEAMS	**7. Background knowledge and skills**	*Students were teamed based on their cognitive levels and background knowledge*	*Students were teamed according their interest*	*Student teams were randomly formed*	*Students were not assigned to teams*
	8. Team Roles	*Students were provided with explicit instruction and activities on effective teaming skills*	*Students were placed on a team with explanation but without considering team member's role*	*Students were chosen for team role without getting explanation*	*Students were not provided with any instruction or activities on effective teaming skills*
	9. Public sharing and Presentations	*Students were provided with opportunities to publicly share their research and designs*	*Students were some-times provided with opportunities to publicly share their research and designs*	*Students were provided one time opportunities to publicly share their research and designs*	*Students were not given opportunities to publicly share their research and designs*
CAREER INFORMATION	**10. Diversity**	*A large number of career fields were emphasized*	*A moderate number of career fields were emphasized*	*Only a few basic career fields were emphasized*	*One career field was emphasized*

3 = *main goal of the activity*
2 = *fairly well addressed*
1 = *slightly addressed*
0 = *not addressed at all*

Representation of Female Role Models in Science

One of our findings during the analysis of the data was the absence of a balanced representation of females and males in the course's activities and speakers. We determined this by analyzing the activities which Mr. Q. used in the classroom: videos, guest speakers, and the selection of topics of the various activities and Mr. Q.'s awareness of gender issues.

None of the selected videos included female engineers as possible role models. In these videos the role of women was either that of a devoted wife and mother or the narrator of the documentary. For example, the movie *Apollo 13* shows all females as the supportive wives of the astronauts.

To represent different disciplines of engineering, Mr. Q. invited guest speakers on two different days from two different engineering fields. These were mining and mechanical engineers. Two guest speakers came to represent mining engineering. One of the speakers was female but she was the Public Relations Representative in her company rather than an engineer. She was passive during the presentation primarily because the male engineer presented mining engineering to the class and he answered most of the students' questions. The second guest speaker was a retired male mechanical engineer who had worked for General Electric for a long time in different states. Unfortunately, his comment about a female engineer spoiled the presentation for the female students. In his presentation, he stated that "I see a couple female students in here. This is very good. Engineering is a very good job for ladies. Engineering plus females is excellent. I know some female engineers, but one of them was a very bad engineer."

None of the activities were chosen by taking into consideration gender sensitivity or the interests of female students. The activities were competitive and the emphasis was on iteration and improvement. The hands-on activities were judged primarily on the basis of the relative quality of the products between the teams. During the airplane activity, students tried to fly their airplanes as far as possible in order to demonstrate the structural quality of their design. For their tower activity, the teacher selected the best tower by comparing each tower's structural strength and design. Female students like to design products that will positively impact society or humans. The activities discussed here were selected by Mr. Q. with little regard to the particular interests of female students. Mr. Q. did not solicit the input of his students as to the nature of the projects that they would like to engage in. According to our rubric criteria, Mr. Q had 1 point for the items of "Representation of collaboration through hands-on activities" because he slightly addressed the sensitivity of gender in this item.

Category	Item	*3*	*2*	*1*	*0*
	2. Representation of collaboration through hands-on activities	*The activities were non-competitive and the emphasis was on iteration and improvement*	*The activities were somewhat competitive but the grading or recognition was based on a criterion-based assessment*	*The activities were competitive but students were not graded with a norm-based assessment*	*The activities were competitive and students were graded in a norm-based assessment*

At the beginning, Mr. Q and the principal invited all students who wanted to take the class to enroll. However, the recruitment did not target the female students in any special way. The announcement of the course did not encourage female students to enroll and none of the activities syllabus took into consideration gender sensitivity or the interests of female students. Even though Mr. Q.'s positive attitude toward female students was encouraging and the fact that he frequently told them that they were good participants in the classroom activities, we believe that many of his actions may not have supported the female students' goal of becoming engineers for the following reasons. He never specifically commented to the female students that they could be good engineers. For example, he did not discuss in the classroom why females are underrepresented in engineering or science. In addition, none of the guest lectures were female engineers who might have provided a role model for the female students in the class. Furthermore, the guest speakers did not make it a point to encourage the participation of females in the engineering field. Mr. Q. did not recognize the need to introduce the subject of female participation in the engineering profession. This is typical of Mr. Q's lack of awareness of gender issues. Thus, Mr Q received 1 point on the rubric for the item "Representation of gender in the instruction, videos and by the guest speakers".

Category	Item	*3*	*2*	*1*	*0*
ROLE MODELS -- DIVERSITY	**1. Representation of gender in the instruction, videos and by the guest speakers.**	*There was an equal representation of males and females in the videos. There were female guest speakers. Females were encouraged.*	*There was an equal representation of males and females in the videos or there were female guest speakers*	***There was not an equal representation of males and female but the issue is discussed***	*All of the engineers presented in the videos were male*

Presentation of How Engineering Affects Society

We reached two conclusions about the presentation of how engineering affects society. One of them was that the videos related to engineering disasters, such as the collapse of a bridge or a building, negatively affected students' perceptions of the engineering profession. The other conclusion was that none of the videos or the classroom discussions addressed how engineering positively impacts society.

After watching several videos about engineering disasters, students made negative comments regarding how hard it was to be an engineer and how much damage faulty engineering caused to human life. Mike said after watching bridge disaster, "Wow!!! Too scary." Tim said, "Why did they not be careful? (in talking about the engineers)". On the other hand, students made positive comments about how engineering was good for society after watching videos that portrayed the numerous benefits that engineering contributed to society. For, example, students liked the documentary: "CNN's Top 25 Technological Innovations." Each student tried to guess which innovation might have been one of the top twenty-five technological innovations of the 20^{th} century. Whenever they guessed correctly, they congratulated each other. Most of the students guessed correctly that "cell phones and the internet" were among the top 25 innovations of the century. Here is what John said: "I could not imagine my life without either a cell phone or the internet." However, Mike, a fellow student, agreed, "How did people live without them?"

Similar patterns were observed in the hands-on activities. After the disaster video, "Collapse of the Bridge", Mr. Q., wanted his students to build a strong bridge, which would not collapse easily because of a natural disaster. First of all, his students worked on calculations and then they decided on the design of their bridge. The students had only one concern during the activity, which was to build as strong a bridge as possible. They hung heavy stones on their bridge at the end of the activity to test it. Mr. Q. did not discuss with his students how engineering affects people's lives positively. The students did not pay sufficient attention to the engineering design process. They only focused on how to eliminate the negative impacts of the products of engineering on society.

Another missing element during the discussions of all of the activities was the insufficient emphasis placed on the contributions engineering made to everyday life. Mr. Q. could have helped highlight this for his students' with a concrete example of how engineering affects society. He may have assumed that the students would make the connections. In our rubric, Mr. Q. received a 1 in terms of "Representation of positive impact of engineering".

Category	**Item**	*3*	*2*	*1*	*0*
SOCIAL RELEVANCE / POSITIVE IMPACT	**3. Representation of positive impact of engineering**	*Activities showed how engineering and technology better people's lives*	*Activities showed both the positive and negative impact of engineering and technology*	*Activities showed mostly the negative impact of engineering*	*The activities were focused on engineering disasters*

Teaching the Iterative Design Process and Design Problem Solving

The course included several design activities that guided students through the design process. Students were first provided with a design problem. There were three hands-on design activities: an airplane project, a tower project and a bridge project.

The airplane project was the first design activity and was completed in two one-hour classes. The design criterion was to build a paper airplane that would travel the furthest horizontal distance. Mr. Q. found this activity on the internet. Students were provided with constraints such as the amount of paper they could use for their design. The teacher provided the students with an airplane design and told them that they could make design modifications. Most of the students built the design provided by their instructor. After the construction of their designs, students tested them during a class competition.

The main issue with the airplane project was that students were not given the opportunity to examine the design problem and brainstorm about different design ideas. Therefore, before starting the next project an engineering professor made a classroom presentation on the design process explaining the steps on problem scoping, alternative designs, construction, testing, modifications, and communication. Students then worked in pairs to build an earthquake-resistant tower. During the tower project, students brainstormed their own design ideas and created their designs conceptually on paper and submitted them to their instructor for feedback. Students used Popsicle sticks to build their towers and were not given any constraints as to the number of sticks they could use. Having no constraints caused two problems. First, students started adding more sticks to strengthen their designs and the designs looked more like art projects rather than addressing the functional requirements. Second, they ran out of sticks during the project and the teacher had to order more.

After receiving feedback from the researchers, Mr. Q. adopted some of the recommendations. He began teaching the iterative design process and design problem solving at the end of the second semester when conducting the bridge hands-on activity. He introduced this activity with the disaster bridge video. His students worked in teams, three students per team. This time, he obtained the materials and asked his students to build a bridge without telling them what he wanted. The students decided on the model of their bridge, but at the end of the activity, each bridge was tested by hanging from it the same amount of weight to compare the strength of each bridge. Before testing each bridge, each team came to class an hour early to test it. If needed, each team modified their bridge model. Mr. Q. helped them with any questions they might have had. We observed positive changes during this activity. The choice of this activity was more in line with traditional engineering and related to students' social life or their interests. In addition, like the other activities, Mr. Q. did not support this activity with discussion nor he did not assess how well his students captured the iterative design process and design problem solving.

Another important finding was that the activities chosen were more craft-like, which was interesting to students, but they wanted more of an engineering orientation. For example, in the first semester, Mr. Q. showed the research assistants how beautiful the towers were. Mr. Q. said: "Look at them. They look like an art project. I would like to do some activities with our art teacher. She would like them." Toward the end of the second semester, the bridge activity was not an art project like the tower activity. During the bridge activity, the students tested the strength of bridge by using different amounts of weights. One of the students asked Mr. Q. what he thought about their team's bridge. He responded: "You are learning how to build a strong bridge." All these explanations about teaching the iterative design process and design problem solving indicates that he should be again awarded 1 point in our rubric because the classroom activities partially emphasized the design approach but were not iterative.

Category	Item	*3*	*2*	*1*	*0*
ITERATIVE DESIGN PROCESS & PROBLEM SOLVING	**4.Process vs. Crafts approach**	*Activities emphasized the iterative design approach with an emphasis on the process*	*Activities emphasized the design approach but were not iterative*	*Activities partially emphasized the design approach*	*Activities emphasized a crafts approach and did not address the design process*

Application and Use of Modeling Tools such as Calculus and Spreadsheets

An important improvement in the quality of the Mr. Q.'s teaching method was the inclusion of calculus and spreadsheets as modeling tools in this classroom. However Mr. Q. did not check his students' background before showing them the connection between mathematics and engineering. Furthermore, he did not make explicit the connections between math and science concepts. We interpreted this action to mean that he assumed that the students would make the connections for themselves despite their grade level. Not choosing suitable activities based on the grade level of students caused obstacles, especially for the freshman.

For example, some of the class activities used Excel as an engineering modeling tool. At the beginning of the semester, students were using a textbook and answering the questions in the book. The differences in the grade levels became apparent during this activity. Lower level grade students had difficulty with this activity because their mathematical background and experience with Excel was inadequate. For example, Jerry (9^{th} grade student) said "This course is hard. It is hard to figure out and find the right symbols. I am using Excel for the first time."

In contrast, some of the eleventh grade students were not working on the assignment in the same activity. The researcher asked one of them why. One student responded that he did it the day before and the assignment was easy for him.

Another activity, mathematics for construction, needed calculus. During this activity, students took measurements of the amount of weight a wooden beam bridge could carry. Freshman students had difficulty solving the problems because they had not taken calculus. They asked for help from the older students but the older students did not want to work with them. One male freshman came to Mr. Q. and he said he did not know how to do it. Mr. Q. talked with him and told him not worry about it. They would learn how to solve the problems at the end of the class. Unfortunately, all the questions were solved on the board by either Mr. Q. or by the older students. Freshmen students just copied the answers to the questions. This deprived the freshmen of an opportunity to receive feedback on their thinking. Some of the freshmen were whispering that they did not understand how to solve the problems at the end of the class. Most of the students looked confused, but none of them raised their hands when Mr. Q. asked who did not understand the questions. Among of the freshmen team, one student asked, “Did you understand how Chris solved the problem?” Another responded, “No, I did not.”

Unfortunately, Mr. Q. chose activities which required a high level of background knowledge in Excel or calculus from his students without considering their grade level differences. Fortunately, recognizing the difficulties with the lower level team of students, Mr. Q. made some changes including activities that were more appropriate for the younger students. The higher level of mathematics required to conduct the activities was an obstacle for the lower grade students because they had not learned calculus and the use of Excel. Based on the observations scored by rubric item “Use Modeling Tools & Methods”, Mr. Q was awarded 2 points because Modeling was embedded in the problem solution process without consideration of students’ understanding. However, he was awarded 0 points for the Assessment of students’ cognitive levels and background knowledge because Students’ prior knowledge and skills were not assessed, and the activities were not modified based on students’ understanding.

Category	Items	*3*	*2*	*1*	*0*
USE OF MODELING TOOLS & METHODS	**5.Embedded Models**	*Modeling was embedded in the design problem solution process and students understood the rationale in using the model*	*Modeling was embedded in the design problem solution process without consideration of students' understanding*	*Modeling was not embedded*	*Modeling was not considered*
	6.Assessment of students' cognitive levels and background knowledge	*Students' prior knowledge and skills were assessed to provide scaffolding*	*Students' prior knowledge was not assessed but some scaffolding was provided*	*Students' prior knowledge and skills were assessed but this information was not used to provide scaffolding*	*Students' prior knowledge and skills were not assessed*

Configuration of Teams

One of the patterns we observed during our analysis was the effectiveness of each team’s composition. The lecture portion of the lessons and the video viewings covered 40 % percent of all activities during the year. Students worked as teams during the hands-on and computer-related activities, which was 60 % of the year. The students seemed to like working as a team because they could be more actively involved in the class activities than they were during the lectures and the videos. We focused on what the team configurations were and how they worked for them in this class because the effectiveness of a team relates to the team's configuration[13].

Most of the time, the same grade level students worked together. They were not given any instruction about how to work in a team at beginning of the semester. The students were also not assigned to a specific role within their team. Each team had three students during the hands-on activities and they worked with a partner during the computer-related activities. Some of the sophomores and all juniors and all seniors worked effectively with their team members. Some of the sophomore and freshmen teams needed help if the activity was too hard for them. At this point, Mr. Q. changed the team memberships. The upper class team of students did not stay with them all the time. At the end of the activity, they came back to their original team because older students found younger students childish in their behavior.

During the bridge building activity, the upper class team of students was talking with each other about the freshmen students.

Chris (12th grade) stated: “I do not want to work with the freshmen group. Look at them, they are childish and they do not take responsibilities. I do not wanna do everything for them.”

Mike (11th grade) said: “Freshmen are playing a game instead of working on their projects.”

However, the freshmen team did not work well because of their lack of background knowledge. For the higher level activities, teams need be reconfigured to help freshmen students learn from older students.

Another finding of the configuration of the teams was that female students worked and sat together all year. They never sat separately. Their third team member was different from time to time, but the female students worked collaboratively with all other team members. If female students needed help, upper class students did not object to helping them out. Mr. Q. was wise in switching around some members of the teams. Female students benefited from the switch which also worked well with others.

During the observations, students listened to the lectures and guest speakers, or they worked with their group on their project either in their classroom, or the computer laboratory. Only once did students make presentations about what they found as a result of their research project. All other times, Mr. Q. collected work without students' giving a presentation. We feel that if students had an opportunity to share their ideas, it would have been more beneficial. By allowing students to see their products' weaknesses and strengths, they would have gained the ability to make presentations in front of the public.

Applying our rubric to the observations for the category of the “Team”, leads to a score of 1 for the item of “Background knowledge and skills” because his student teams were randomly formed. For the item of “Team Role” he received a 1 because his students were chosen for team roles without an explanation for those roles. He also received a 1 for “Public sharing and

Presentations" because his students were provided with only one opportunity to publicly share their research and design.

Category	Items	*3*	*2*	*1*	*0*
TEAMS	**7.Background knowledge and skills**	*Students were teamed based on their cognitive levels and background knowledge*	*Students were teamed according their interest*	*Student teams were randomly formed*	*Students were not assigned to teams*
	8.Team Roles	*Students were provided with explicit instruction and activities on effective teaming skills*	*Students were placed on a team with explanation but without considering team member's role*	*Students were chosen for team role without getting explanation*	*Students were not provided with any instruction or activities on effective teaming skills*
	9.Public sharing and Presentations	*Students were provided with opportunities to publicly share their research and designs*	*Students were some-times provided with opportunities to publicly share their research and designs*	*Students were provided one time opportunities to publicly share their research and designs*	*Students were not given opportunities to publicly share their research and designs*

Career Information

Mr. Q. used different techniques to introduce different types of engineering in his lessons. He did through guest speakers, presentations, and PowerPoint projects. Mr. Q. also made a good attempt at introducing different types of engineering to his students by helping them during their career decision activity. Unfortunately, only a limited number of basic engineering careers were discussed and none of the options related to activities carried out by the students.

Mr. Q. invited three engineers to give more practical information about how to become engineers in real life. One was a mechanical engineer, another a retired electrical engineer, and a third was a mining engineer. These engineers shared their real-life experiences with Mr. Q.'s students in terms of the obstacles and rewards they might face when becoming a successful engineer. Even though it was a good idea to invite guest speakers into the classroom to inform students, all of the engineers were chosen from the specific engineering fields, such as mechanical or electrical engineering. There was not sufficient diversity to represent a broader range of engineering fields to the students.

Mr. Q. wanted his students to contact at least one engineer who would be willing to participate in an interview with them. Mr. Q. gave his students 15 specific questions to ask their interviewees. The students did not have ample opportunity to process, present or critique the information derived from this assignment. In another activity, the students prepared PowerPoint presentations about one of the engineering fields of their choice. Mr. Q. wrote nine different engineering fields on the board previously and students signed up to research one of them. These majors were: Bioengineering, Chemical Engineering, Civil Engineering, Computer Engineering, Electrical Engineering, Environmental Engineering, Industrial Engineering, Materials Engineering, and Mechanical Engineering. These engineering fields were diverse and provided students the opportunity to focus on a field of their interest. They had handouts, which they needed to follow to prepare the PowerPoint presentation. Each Power Point presentation was limited to seven slides. They searched the specific information about their chosen engineering field from the internet. Again, it was good activity in terms of learning information about one of the engineering fields, but Mr. Q. limited his students' vision by specifying which engineering fields his students had to choose. In addition, from a pedagogical perspective, he did not support any associated activity with discussion. The students had limited insight as to what their chosen field might be and how relevant it was to the students' specific interests. All these observations support the rubric scores of 1 for the "Career Information" and "Diversity" because only a few basic career fields were emphasized during the course.

Category	Item	*3*	*2*	*1*	*0*
CAREER INFORMATION	**10. Diversity**	*A large number of career fields were emphasized*	*A moderate number of career fields were emphasized*	***Only a few basic career fields were emphasized***	*One career field was emphasized*

Conclusions and Recommendations

Based on data collected in this study, the instructor of this program, Mr. Q. had both strengths and weaknesses in developing and implementing this engineering magnet program.

One of his strengths was his good intentions and the fact that he wanted to do his best in terms of increasing the students' participation in his classroom activities. His enthusiasm about the class drove him to put in a lot of time and energy. He interacted with his students as a facilitator during the hands-on activities. He maintained the students' interest with several hands-on design activities, such as building an airplane, a tower, and a bridge. He also organized Excel spreadsheet activities, guest speakers, field trips, readings about the design process, and team presentations. His students' participation was high during each class activity, except during the lecture portion of the lesson. He also revised the curriculum in terms of the kinds of design activities that provided the most realistic experiences. At the beginning, chosen activities were more like crafts but at the end they were more engineering oriented.

On the negative side, Mr. Q. neglected some aspects of the class which negatively affected the success of this program and his teaching. A key missing part of his teaching was that Mr. Q. did not pay sufficient attention to the topics of the activities in the class discussions. Also, none of the video presentations nor the activities were adjusted to reflect the interests of the students based on their questions or discussions. Furthermore, Mr. Q. did not ask any questions about the impact of engineering on daily life to help his students to make the connection between engineering and society. For example, after any of the video presentation, hands-on activities, Excel or spread sheet activities, he did not ask any questions to learn what his students thought about any of the activities. He assumed they would both learn and make connections after each activity on their own.

Another negative factor in his teaching was that he did not consider either gender or minority interests, because none of the activities related to their daily lives. It is obvious that nowadays many female engineers work successfully in the different fields of engineering and that there are many fields that would appeal to the females. Unfortunately, the classroom activities were not s designed to highlight women in engineering or to appeal to females. They were two missed opportunities that could have addressed this. None of the guest speakers and videos included successful female engineers. Secondly, females' interest in science could have been supported by socially relevant activities as opposed to competitive ones. The small number of females in the program has been addressed in new approaches to recruitment. The four female students produced a video for recruitment and became part of the recruitment team. Unfortunately, there was not enough evidence to show that female engineers could be successful in engineering. Furthermore, the guest speakers and the videos negatively affected the representation of female role models in science and engineering.

Portraying the benefits of engineering positively affects the attitude of students regarding the role of engineering in society. Unfortunately, most of the chosen videos focused on disasters that were the result of engineering mishaps and miscalculations. The students had negative comments about engineering after each disaster video. This discourages students about being successful in the field of engineering. Mr. Q. assumed that his students had already learned basic engineering and had the required mathematical knowledge, such as calculus, and Excel. In addition, Mr. Q. chose classroom activities geared for students who have already decided to become engineers for their future careers. He did not find out what his students' interests or backgrounds were in terms of engineering at the beginning of the classroom via discussions or the questionnaires. He assumed that the school had taken steps to address grade level and maturity issues on prior courses and that the school requiring increasing levels of math and science ability. Mr. Q. was also challenged because some of the activities were too easy for upper class students, or too hard for lower class students. All students who wanted to take the class were allowed to do so because, according to Mr. Q., the principal was concerned that there would not be enough students to fill it. However, the opposite happened. Also, Mr. Q. told us that the guidance counselor thought that, since it was a hands-on class, it would be good for special education students and others who needed an elective. These problems have been addressed by more selective enrollment criteria.

The engineering program could be improved in a number of ways. Grade level differences should be taken into consideration in terms of mathematics and science backgrounds by establishing maturity criteria and pre-requisites. For an engineering course introducing different engineering fields and classroom discussions on the engineering design, the discussions on the importance of technology in our daily lives might be more beneficial for younger students. Lessons on the application of mathematics and science principles would benefit older students. Furthermore, the teacher should make explicit the connections between math, science and engineering, rather than assume students will make the connections for themselves. We suggest working more closely with the math and science teachers by coordinating activities and topics so that teachers can make connections by referring to what is happening in one another's' classrooms.

Team configuration and activities should be chosen with the consideration of each team's level of students. Mr. Q. did not explain how teams work. He did not assign specific roles for each team member and let them work without assigning specific roles. Assigning roles would increase the level of participation of each member of the team. Rotation of each team member's assignment would increase the different grade level interaction, especially for female students. This way, freshman students could have more communication opportunities with upper class students to ask more questions comfortably and easily, rather than direct questions to the teacher.

Mr. Q. supported the magnet engineering program by providing career related information to his students. His aim was to encourage his students to explore what kind of engineering fit their interests. However, the structure of his teaching and the options available to students were limited by the content of his lectures, the type of guest speakers invited, the power point activity, and the interviews with the engineers. He could have encouraged or guided his students to research different types of engineering compared to the traditional types of engineering such as mechanical, and electrical engineering. In addition, he could have spent time discussing his students' presentations and what they discovered during their research projects or what type of engineering fit their interests.

Our findings were directly related to sociocultural theory. During the team activities, students related better to one another as well as to their teacher. The hands-on activities and the joint efforts in the preparation of the Power Point assignments provided an environment conducive for the students to interact comfortably among each other and with their teacher. Most of the time, the same students, only at the same grade level worked together. We would recommend that different students from varying grade levels interact with one another. This way, they could benefit from the experience and knowledge of other students at a different grade and age level. In addition, the tool mastery had the potential for learning or development when referring to the issues with the Excel assignments. For example, the teacher taught the students how to use tools but did not consider the consequences of a student not learning the tool. The teacher interacted with students most of the time for the hands-on activities. He walked around and he helped them during the activities, but he did not discuss the reason for any of the activities or their importance or how to address the problems the students had. The teacher was missing opportunities to build knowledge, especially by discussions related to the role of female engineers in society.

The rubric we developed based on the goals and class features related to Mr. Q.'s class should prove to be very useful in analyzing a large set of complex data. In our opinion, the rubric provides useful information for those interested in teaching similar innovative courses. If teachers review our findings and implement them, there is the potential to help to design a course that would avoid the issues and pitfalls that Mr. Q., had to face. Hopefully, it should help them better educate and guide their students.

Bibliography

1. National Academy of Engineering (2004). *The Engineer of 2020 Visions of Engineering in the New Century.* Washington D.C.: The National Academies Press.

2. Roth, W-M. Learning science through technological design. *Journal of Research in Science Teaching, 38,* (2001) 768-790.

3. American Association of Advancement in Science (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

4. National Research Council (1996). *National Science Education Standards.* Washington, DC: National Academy Press.

5. International Technology Education Association (2000). Standards for technological literacy: Content for the study of technology. Reston, VA.

6. Yaşar, Ş., Baker, D., Robinson-Kurpius, S., Krause, S., & Roberts, C. (2006). Development of a survey to assess K-12 Teachers' perceptions of engineers and familiarity with teaching design, engineering, technology. *Journal of Engineering Education*, 95(3) *205-216.*

7. Vygotsky, L., S., (1994) Thought and language. Cambridge, MA: MIT. Press

8. Hiebert, J., Carpenter, T.P., Fennema, E., Fuson, K.C., Wearne, D., Murray, H., Olivier, A., & Human, P. (1998). Making sense: Teaching and learning mathematics with understanding. Portsmouth, NH: Heinemann.

9. Erikson, F. (1986). Qualitative methods in research on teaching. Handbook of research on teaching. M. C. Wittrock. New York, NY, Macmillan Publishing Co.

10. Creswell, J. W. (1994). Research design: Qualitative &quantitative approaches. Thousand Oaks, CA: Sage.

11. Merriam, S. (1998). Qualitative research and case study applications in education. San Francisco, CA: Jossey-Bass Publishing.

12. Walsh, M. (2003). Teaching qualitative analysis using QSR NVivo. *The Qualitative Report,8*(2), Retrieved [01.05.07], from http://www.nova.edu/ssss/QR/qr8-2/walsh.pdf.

13. Johnson, D. W., & Johnson, R. T. (1999). Learning together and alone: Cooperative, competitive, and individualistic learning. Boston: Allyn & Bacon.