# 2006-622: INTEGRATING COURSES THROUGH DESIGN PROJECTS IN A HIGH SCHOOL ENGINEERING SUMMER PROGRAM

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# Integrating Courses through Design Projects in a High School Engineering Summer Program

**Abstract:**

Introducing real-life engineering design projects and integrating five courses into the Engineering Summer Program (ESP) for high school students made a difference in student learning, according to data collected during the summer, 2005. While the program at University of Wisconsin – Madison has existed since 1977, 2005 was the first summer that integration through engineering design was a central theme. The goal was to encourage the eighteen students to better appreciate a) why their math, chemistry, physics, technical communication and introduction to engineering courses are important in engineering studies and b) how these courses work together to help students develop engineering skills. Assessment instruments included beginning, middle, and end-of-design experience questionnaires, videotapes of student presentations, and a reflective letter to their parents. Through the data collected, the paper answers the following questions: a) Are real-life student design projects an effective means of integrating different courses? b) Did the real-life student design projects provide better student understanding of engineering in general? c) Did the exercise of designing and presenting projects, stimulate student interest in science and engineering careers? This pilot assessment plan will be used to improve the program as well as to assess student learning even more effectively during 2006. The paper describes a brief background of ESP, each of the five courses, the design projects, the assessment instruments, the results and analysis, and recommendations for the 2006 Engineering Summer Program.

**Program Overview: Engineering Summer Program (ESP)**

The University of Wisconsin-Madison College of Engineering hosts ESP, a seven-week residential program for high school sophomores and juniors. It is a pre-college educational enhancement outreach—a summer bridge program for underrepresented high school students. The ESP program is the oldest of the diversity programs in the College of Engineering at the University of Wisconsin-Madison. It has served as the primary recruitment tool for the college for more than twenty years. The goal for ESP is to prepare high school students for college study in the field of engineering and science, and to attract these students to the UW-Madison. The program targets students from traditionally underrepresented backgrounds including African American, Latino, Native American, Cambodian, Laotian, Hmong or Vietnamese. We also select female students who would be first generation college students.

The students are exposed to basic foundational courses that are fundamental to the engineering discipline: pre-calculus or calculus depending on the background of the student, physics, chemistry, computer science, and technical writing. Students are exposed to various engineering fields through short discipline specific laboratories and faculty presentations in a course called Introduction to Engineering. Approximately two to three industry tours are planned during the course of the summer, so that students can see engineering in action. Companies that have offered tours in the past are Kimberly Clark, General Motors in Janesville, Harley Davidson and GE Medical Systems. Refer to Appendix A for the program description sent to the students.

The students enjoy the activities in this course and plans are to enhance and incorporate additional hands-on laboratories for the students in coming years. In 2002, a laboratory course in physics was added to the curriculum. Over the past few years enrollment during the summer ranged from as low as 16 to as high as 24 students. We currently accept 23 participants.

The program recruits students from across the country. Applications are sent to math teachers, physics teachers, and guidance counselors at high schools, and are due in mid to late April. The students must pay for their transportation to the University and a $50 application fee. The program pays all other expenses. The program, though sponsored by the UW College of Engineering, has been funded entirely by private and corporate donations. GE Medical Systems has been the main sponsor of the program from 1996 through 2000. The five-year funding cycle ended last spring and we are currently pursuing other avenues of support for the coming years. The program typically costs $ 82,000 of which around 50% is dedicated towards student expenses, around 40% towards instructional expenses and the remaining towards operational and miscellaneous expenses. The budget per student is around $4000. Refer to Appendix B for a detailed description of a sample budget.

**Metrics/ Measurement of Success**

In 2002 the Diversity Affairs Office set out to track the results of four minority outreach programs for graduate and undergraduate students. Of the four programs run by the College, the ESP program is our most successful recruitment program. From 1996 through 2000, over 31% (30 out of 95) of all ESP participants enrolled in the University (UW). From 2001-2003 we have been able to recruit 50% of the ESP participants to the UW. Of all the engineering summer programs, the ESP had the most clearly defined mission: the educational enhancement and recruitment of target underrepresented students in engineering. See Appendix C that shows the number of ESP participants that apply and are accepted to the UW-Madison, and are currently enrolled.

The College of engineering continues to measure the results of the program by tracking the following data. Of the high school senior participants:

1. How many choose to enroll in the UW Madison College of Engineering?
2. How many enroll in other colleges at the UW Madison?
3. How many enroll in science and engineering colleges outside of the UW?
4. How many successfully graduate from college, and how many enter the technical fields?

Refer to Appendix D for the above information.

The Engineering Summer Program has been offered for 28 years. During this time, the program has changed in its goal, from producing college graduates to producing UW College of Engineering graduates, but one thing has remained consistent: ESP and its long-standing effort to create a more diverse technical workforce is supported by investment of industries who are committed to this goal.

## Value of Integration

The ESP programs consisted of individual courses; however, it did not emphasize curriculum integration. Curriculum integration, according to Richardson and others, 1996, promotes a broad-based level of understanding rather than a more narrow discipline specific understanding.[1] During ESP 2004, an attempt was made to integrate two courses: Chemistry and Technical Communication. Students were encouraged to work in groups of two or three and write a research paper and do a presentation on topics in which they were able to identify some of the principles from chemistry they had learned so far and were of interest to them. Some of the topics the students worked on were: 'Fuel Cells', 'Deforestation', 'Organ Transplantation', and 'Genetic Intervention'. The students enjoyed working on their paper and also got to learn from other students about their research topics. We observed this enthusiasm and active student participation in the activity. This experience encouraged us to take a step further towards broader curriculum integration.

Research showed us several integration models at the undergraduate level. For example, a thrust for integration of curriculum consisting of chemistry, English, engineering, math and physics has being emphasized by Morgan, 1997, to produce engineers who can more effectively solve increasing complex problems.[2] Secondly, Richardson, 1996, used a series of design projects to give students a "taste" of engineering and achieve curriculum integration.[1] In addition to these models, interaction with faculty affiliated with the Delta program at UW-Madison [3] provided impetus for broader curriculum integration. The three core principles of Delta were used as guidelines towards the integration process. These principles are a. Teaching-as-research, b. Learning community and c. Learning-through-diversity. [3]

Building on these undergraduate models and the Delta principles, the ESP 2005 program goal was to integrate all five courses through design projects. The students were grouped in teams of four or five students and assigned various design projects. The instructors from different courses helped the students identify and apply the principles of physics, chemistry and mathematics involved in these projects. While the instructors from introduction to engineering and chemistry helped design the actual projects, the instructor from technical communication helped students prepare for their final presentation and project demonstration. As discussed by Barrow, 1995, curriculum integration of subjects and engineering applications immediately provided a new perspective for mathematics and science.[4] Hence one of the goals was to encourage the students to identify principles from mathematics and sciences that they could apply in these projects.

## Design Projects

The four different design projects on which the students worked for three weeks are described below in the table below. And figure 1 shows how the design projects help integrate all five courses as well as stimulate student interest in science and engineering and lead to better student understanding of the engineering profession.

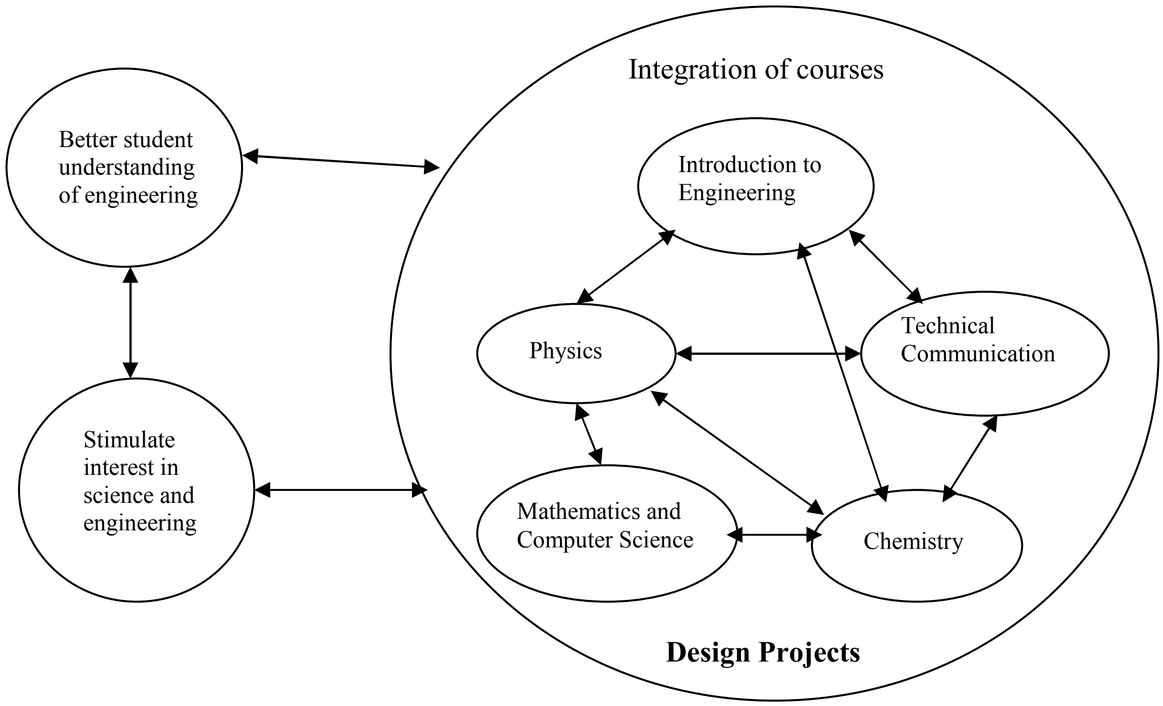


Fig1. The ESP integration model

| Project | Problem Description |
|---|---|
| **Tractor Ladder Extension** | As farmers get older, they have trouble stepping up to the ladder for their tractors. An extension to the ladder (bottom of ladder to the ground) would be a very useful tool for this subset of farmers. Your task is to design and build an 18 inch extension that hooks into the bottom of the existing ladder and when weighted holds steady against the existing structure. It must be safe, durable and light weight. The extension will be built to a wooden prototype provide by the class instructors. |
| **Low-Voltage Conductivity Tester** | A conductivity tester for classroom demonstrations uses 120 volts AC. This is unsuitable for handling by inexperienced users (children). We would like a similar conductivity tester that uses low-voltage AC so it can be handled safely. The device is used to test electrical conductivity of various salt solutions in a chemistry laboratory. Your team's task is to come up with a preliminary design, present pros and cons to your approach, and make recommendations as to how you would improve upon the concept. You will build a prototype on an electronics 'bread board'. |
| **Table Baby Seat** | You are to design a baby seat that hooks up against a table and safely holds the child while weighted. It must be safe, durable and light weight for easy parental use. We are just looking for a structural prototype; the seat does not have to be cushioned. It must hold a 50 pound child. |
| **Cane Holder** | This is a safety strap that can go around the person's wrist and cane and allow easy retrieval of the cane if dropped. |

## Research Questions and Methodology

Teaching-as-research (TAR) involves the deliberate, systematic, and reflective use of research methods to develop and implement teaching practices that advance the learning experiences and learning outcomes of students/participants and teachers/facilitators.[3]

Conceptual steps in the teaching-as-research process are:

1. Learning foundational knowledge (What is known about the teaching practice?)
2. Creating goals for better student/participant learning (What do we want our students/participants to learn?)
3. Defining measures of success (What evidence will we need in order to determine whether students/participants have achieved learning goals?)
4. Developing and implementing teaching practices (What will we do [in and out of the classroom] to enable students/participants to achieve learning goals?)
5. Collecting and analyzing "data" (How will we collect and analyze information to determine what students/participants have learned?)
6. Reflecting, evaluating, and iterating (How will we use what we have learned to improve our teaching?)[3]

We can examine the TAR approach mentioned above through the Kirkpatrick's four-level model for evaluation of a training program, which is shown in figure 2:

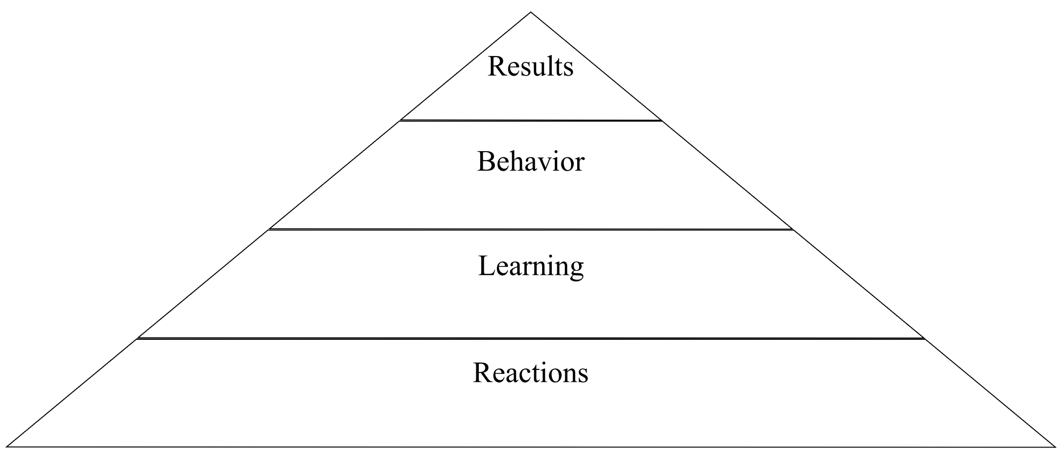


Fig 2. Kirkpatrick's four-level model for program evaluation

The four levels represent a sequence of ways to evaluate programs and each level builds on the experiences and outcomes from the previous level. These four levels are briefly described below[5]

**Level I- Reaction:** Evaluation at this level measures how those who participate in the program react to it.

**Level II- Learning:** Learning can be defined as the extent to which participants change attitudes, improve knowledge, and/or increase skills as a result of attending the program

**Level III- Behavior:** Behavior can be defined as the extent to which change in behavior has occurred because the participant attended the training program.

**Level IV- Results:** Results can be defined as the final results that occurred because the participants attended the program.

We modeled the summer ESP 2005 experience as a research problem using both the TAR and Kirkpatrick model described above. For example, we collected and analyzed the data (step 5, from the TAR approach); this helped us to gauge the extent to which participants change attitude improve knowledge and increase skills as a result of participating in ESP (Level II – Learning, from the Kirkpatrick model). We recognized the need for systematic approach for evaluating ESP 2005, so we launched this pilot study with pre and post questionnaires.

The figure 1 shows how we envisioned the interaction among the different courses. We were also interested in the three research questions mentioned below about the curriculum integration process.

a. Are real-life student design projects an effective means of integrating different courses?
b. Did the real-life student design projects provide better student understanding of engineering in general?
c. Did the exercise of designing and presenting projects, stimulate student interest in science and engineering careers?

The students were asked to complete three questionnaires, Questionnaire I was at the beginning of their design project, Questionnaire II at the middle and Questionnaire III at the end of their project design experience. The students were also videotaped during their final project demonstration and presentation. And the students were asked to write a reflective letter to their family describing some of their experiences at the ESP program. Through these, questionnaires we received student responses and their perception towards the program. These questionnaires helped us gauge student in terms of their critical thinking and ability to apply principles from chemistry, physics and mathematics into the design projects. The presentation and demonstration of the projects given by the students and the question and answer session following the presentation helped us evaluate the transfer that occurred from the ESP program to the participants. One of the goals of the program was to help students make informed decision for the career path they plan to choose (Level IV – Results, from the Kirkpatrick model, step 6, from the TAR approach).

This paper discusses the observations and results from the questionnaires completed by the students. Once again the goal of these questionnaires was to answer the research questions mentioned above and to evaluate the success of this pilot program and provide recommendations for future ESP activities. The analysis and conclusions section provides the analysis of these questionnaires.

## Analysis and Conclusion

Miles and Huberman, 1984, provide a useful reference for data representation and analysis.[6] Below are the data, analysis and conclusions for each of the three research questions. We recognize that such data was not collected for the past ESP programs hence we cannot provide a direct comparison between the current program and the program without the use of the design projects. However we plan to track the college participations of the students.

Research question I: **Did the real-life student design projects provide better student understanding of engineering in general?**

Analysis of student responses shows that student understanding of engineering are categorized into several themes. The ideas about product design, social aspects and integration of math and science in engineering were reinforced during the design experience and observed in the student responses under different themes described in Table IA.

| **IA. Describe in 3-4 sentences what engineering means to you** | | |
|---|---|---|
| **Themes & responses<br>Questionnaire I** | **Themes & responses<br>Questionnaire II** | **Themes & responses<br>Questionnaire III** |
| **Betterment of humankind**<br>Finding out how to better process for the betterment of humankind. You design things and invent things. There's a lot of math and science involved too. | **way someone could improve daily life**<br>Engineering provides society better and more efficient processes and equipment to make life easier. | **making a difference in the world**<br>Engineering is making a difference in the world by creating things that have not yet been created. |
| **Process of designing and creating new things**<br>Engineering means finding solutions for difficult problems. It means working together to discuss simple and efficient ways of problem solving. Engineering means thinking of crazy ideas and making them work. | **designing new products**<br>Engineering means problem solving and being able to make the best products from different ideas. The results may not be perfect but engineering is how far along you can get on a project in a certain amount of time. | **process of designing products and processes**<br>Engineering is the process of designing products and processes that will be used by others |
| **Encompassing science and math**<br>Engineering is something that encompasses the science and math in order to build things to better society. | **applying physics and math to everyday objects**<br>Designing and applying physics and math to everyday objects. It is constructing and designing things to help everyday life. | **use both math and science in my everyday career**<br>Engineering means the opportunity to use both math and science in my everyday career. It allows me to work with others to design products for everyday use. I would be able to learn to work with others to use math and science in applicable ways. |
| **Others**<br>it's a great science field but I don't want to be an engineer | **Others**<br>Engineering is in everything, everything is engineering. | **Others**<br>Engineering= everything in life, including life |

Note: Not all students responded for Questionnaire II.

Based on the responses collected at the beginning, middle and end of the project periods, the results show that the number of students enjoying the group work increased. Refer to Table IB.

| IB. **Do you enjoy working in a group: Yes or No** | | | |
|---|---|---|---|
| **Questionnaire** | **Yes** | **No** | **Maybe** |
| **I** | **10** | **7** | **1** |
| **II** | **12** | **3** | **0** |
| **III** | **13** | **5** | **0** |

Note: Not all students responded for Questionnaire II.

Regarding what individuals liked the most about group work, all the students recognized the importance of group work into the design decisions. By the end of the experience the student comments fell into two categories; the first is the endless number of ideas and the second is how the ideas informed the design decisions. Refer to Table IC.

| IC. **One aspect of group work you liked the most** | |
|---|---|
| **Themes &response<br>Questionnaire I** | **Themes &response<br>Questionnaire III** |
| **More ideas**<br>I have the chance to listen to other intellectuals with great ideas because everyone thinks differently.<br><br>**collaborating the ideas**<br>Hearing the ideas of others and then collaborating the ideas to be productive.<br><br>**Others**<br>Pretty much nothing. | **Ideas were endless!**<br>We came up with more ideas, so it was easy for us to build the table baby seat. "Two head are better than one".<br>**Ideas were worked into the decision**<br>We could communicate. It seemed like we didn't have as many problems that other groups had. We worked good together and got the task done. |

Results in Table ID show that the challenges remain to involve all the students consistently throughout the project. For example, even by the end of the experience, several students commented that, "Some people ended up doing less work and not taking the initiative or wanting to lead."

| ID. **One aspect of group work you disliked the most** | |
|---|---|
| **Themes &response<br>Questionnaire I** | **Themes &response<br>Questionnaire III** |
| **Debating, no agreement**<br>Not having leadership, too much leadership, or one person taking control and doing everything without the group consensus<br>**everybody don't want to work**<br>Sometimes, I am left to do the work on my own, because I don't want to fail in whatever it is I am doing<br><br>**Others**<br>Sharing grades/work | **Disagreeing on what to do**<br>When the team fight each other because one person wants to do one thing, but somebody else wants to do something different<br>**trouble getting everybody ready to work**<br>Some people ended up doing less work and not taking the initiative or wanting to lead<br>**Others**<br>Actually, I think everything was OK. I mean … there wasn't anything I disliked of working in group |

Results in Table IE indicate that the design process involved in the project provided students a much detailed idea regarding the steps involved in commercial product design. The hands-on experience reinforced the concepts regarding product design they had learned in the classroom sessions.

| IE. **Steps involved in designing a commercial product** | |
|---|---|
| **Themes & responses<br>Questionnaire I** | **Themes & responses<br>Questionnaire III** |
| **<u>Understand the problem, brainstorm, plan and execute</u>**<br>First you need to establish a need and what the problem is, you then brainstorm and afterwards pick out which ideas you think will work. You have to build prototypes and adjust them until you get something that works.<br><br>First, you have to outline what the product designed will be, various requirements, etc. Then, you have to brainstorm many ideas, even if they won't work. Then you have to narrow your ideas down to a design or two. Then you test your design, you fail then you try again | **<u>Brainstorm, evaluate, design, build, test</u>**<br>One must identify the problem to be solved, then brainstorm ideas for solving it. After brainstorming ideas can be evaluated. Finally, you create a design, test it, then design and test again ( and again and again)<br><br>First of all you come up with a lot of ideas. 'Brainstorm', then you pick up the ideas that are more easy to use and we try to start building. Also you have to check, that what you are doing is what your client want, because you don't want to do something that your client won't like. Then you just build it and then you load it and if it doesn't work correctly, then you just try one more time and try to make it better. That's how engineering works |
| **<u>Others</u>**<br>I don't like following rules like that. I usually get an idea and go with it. Its more fun and effective that way<br><br>I don't know them! | **<u>Others</u>**<br>I don't know |

**IF. On the scale of 1-10 rate your presentation skills (Refer to Appendix E)**

From Appendix E it is seen that, 72% of students rated 6 and higher as their presentation skills at the end of the project, as compared to around 94% at the beginning. The distribution indicates that the students became more aware of the skills they lack for effective presentation and demonstration of their project. On the other hand, it also conveys that this may be one of the areas the program needs to pay attention to provide students with a much richer engineering experience. One of the ways to improve the presentation and communication skills of the students would be to make the entire faculty aware of the concern. The Technical Communication's faculty in this case would take leadership role to provide more opportunity and encouragement to the students with their communication skills.

**IG. On the scale of 1-10 rate your previous and present experiences of working in a group (Refer Appendix F)**

Data from Appendix F show that 83% of students rated 6 and higher as their *present* experience working in a group on the project, while 72% of students rated 6 and higher as their *past* experience working in a group. More students ended up enjoying the group work and stayed motivated as they completed their design projects.

**Research Question II:** **<u>Are real-life student design projects an effective means of integrating different courses?</u>**

Table IIA shows that around 78% of the students were able to identify principles of physics they thought they could apply to their project.

| IIA. Are you learning any concepts from physics course that you can apply to the project? | | | |
|---|---|---|---|
| Questionnaire # | **Yes** | **No** | **Physics principles (questionnaire II)** |
| II<br>n=14 | 11 | 3 | Resistance and voltage relation<br>Flow of electricity<br>Force = mass * acceleration<br>Applied forces and how it affects the distance(s) and amount of work needed to accomplish the task. This was applied to the angle at which the ladder should be and the weight of the farmer applied upon the ladder. |

Note: Not all students responded for Questionnaire II.

Table IIB show how an idea or a concept about a process at the beginning of the design experience was transformed into a specific formula which they implemented into their project.

| IIB. Are you learning any concepts from physics course that you can apply to the project? | | |
|---|---|---|
| Projects | Principles (questionnaire I) | Principles (Questionnaire III) |
| Tractor Ladder Extension | Calculating the force put upon the ladder, calculating the static<br>I might apply some mechanical concepts | Work= force * distance and static calculations<br>Work= force*distance, static calculations |
| Low voltage conductivity tester | Everything<br>The flow of electricity through wires<br>Currents and voltage electricity | V=I*R<br>Ohm's law, V=I*R, we used it to calculate resistance<br>Electricity Ohm's law |
| Table baby seat | Forces exerted and the maximum force allowed by an object<br>Force of gravity that will prevent baby from falling from a chair | Torque= Force *distance,<br>Force = mass *acceleration<br>Torque= Force *distance,<br>Force = mass *acceleration |
| Cane Holder | Friction/strength | Friction |

Data in Table IIC show that 64% of students were able to identify the principles of chemistry involved with the project. One of the reasons fewer students were able to identify the chemistry principles might be due to the nature of their project since some projects did not incorporate chemistry as much as others.

| IIC. Are you learning any concepts from chemistry course that you can apply to the project? | | | |
|---|---|---|---|
| **Questionnaire #** | **Yes** | **No** | **Chemistry principles** |
| II<br>n=14 | 9 | 5 | In chemistry, I learned that the composition of a material determines how that material reacts to several conditions in which it may be placed. We chose steel due to its stability.<br>The compositions of materials, which make us look for the best solutions to look for materials that could be more useful to build something (like steel).<br>Different metals with conductivities of various salt solutions.<br>How salt solutions can conduct electricity, ionic solutions. |

Note: Not all students responded for Questionnaire II.

The responses in Table IID indicate the students were able to use their ideas about material composition and characteristics to determine the type of material they should use for their projects. Similarly they got a better understanding regarding conductivity of salt solutions.

| IID. Are you learning any concepts from chemistry course that you can apply to the project? | | |
|---|---|---|
| Projects | Principles (Questionnaire I) | Principles (Questionnaire III) |
| Tractor Ladder Extension | Material composition and strength<br>The principles for chemistry might be welding in order to gather more than one element | Characteristics and composition of different metals<br>The product we made our design of steel, easy to weld |
| Low voltage conductivity tester | The basics of the conductivity of various metals<br>Conductivity- if stuff has a charge and can carry current | Conductivity of salt solutions<br>Conductivity – which is how electricity travels through the solution |
| Table baby seat | Dimensions of the baby so it could fit in the baby seat | The deterioration of wood based on the saliva falling on it |
| Cane Holder | Materials used, durability | Nylon fabric is strong |

Table IIE show that 92% of the students were able to identify some mathematical concepts they could apply to their projects.

| IIE. Are you learning any concepts from mathematics course that you can apply to the project? | | | |
|---|---|---|---|
| Questionnaire # | **Yes** | **No** | **Mathematics principles** |
| II<br>n=14 | 13 | 1 | In pre-calculus, I learned the concept of sin, cosine etc. During the engineering project , we were forced to apply these functions into calculations, in order to figure out the angle at which the hook on our flares should be welded<br>We had to calculate the angles at which pieces would attach and use our calculations to determine the dimensions of our ladder<br>Using the Pythagorean Theorem to get the dimensions between the steps<br>Equations (Ohm's law) and applying it to our project (solving these equations)<br>Dimensions, measuring, algebra, calculations |

Note: Not all students responded for Questionnaire II.

The responses from Table IIF indicate that the students had an opportunity to apply principles from trigonometry to determine the size of object they plan to use and geometry of their final product. Also they got to practice arithmetic and algebra when they implemented formulae from Physics.

| **IIF. Are you learning any concepts from mathematics course that you can apply to the project?** | | |
|---|---|---|
| Projects | Principles (Questionnaire I) | Principles (Questionnaire III) |
| Tractor Ladder Extension | Pythagorean theorem<br>Calculus | Calculations of permissible size of flair using trigonometry<br>The measurements and calculations of the ladder |
| Low voltage conductivity tester | Ohm's law: V=I*R<br>That one dudes law | Applying Ohm's law<br>Figure out mathematical aspects such as Ohm's law |
| Table baby seat | The dimensions of a chair<br>The measurements and dimensions | Finding the dimensions of wood and how much room we would need for a child<br>Actually we just worked with math doing some kind of calculations about the dimensions of the baby, so it would able to fit in the seat |
| Cane Holder | Pythagorean Theorem not stars and clouds. Really just overall measuring methods for lengths and widths<br>Length/size | Formulas and measurements<br>Length of strap |

Table IIG show that as the students progressed working on the projects, almost all the students surveyed agreed that the group projects helped them learn more about the applications of physics, chemistry and mathematics in day-to-day life.

| **IIG. Do you think working on a group project will help you learn more about the applications of physics, chemistry and mathematics in day-to-day life?** | | | | |
|---|---|---|---|---|
| **Questionnaire #** | **Yes** | **No** | **No idea what the question means** | **Sort of** |
| I n=18 | 15 | 2 | 1 | 0 |
| II n= 14 | 13 | 0 | 0 | 1 |

Note: Not all students responded for Questionnaire II.

**Research question III: <u>Did the exercise of designing and presenting projects, stimulate student interest in science and engineering careers?</u>**

Table IIIA indicate that the students got an opportunity to be better informed about the career path they would choose. In some cases the students got exposed to more areas of engineering which they might have not considered before. However, some other students were able to narrow down and emphasize a particular engineering path of interest to them.

| IIIA. What field in engineering interests you the most? | | |
|---|---|---|
| Engineering stream interested in Questionnaire I | Engineering stream interested in Questionnaire III | Student responses from Questionnaire III |
| Mechanical | Mechanical | I like working with things that people use everyday and knowing how things actually work. |
| Civil | Mechanical, Civil | Mechanical engineering is interesting to me because I realized from ESP that I like to figure out how things work and what the best way to make them is. Civil Engineering is interesting to me because I like drawing and design. I am also thinking of some kind of architecture. |
| Computer | Computer, Electrical, Environmental | I care deeply about conservation of the environment and sustainability. I also have a big interest in computers and electronics. |
| None really | Computer (maybe) | I've had an interest in computers plus it seems interesting |
| Nuclear, Mechanical, electrical, aerospace | Mechanical | I like to actual building and design elements |

**IIIB. On the scale of 1-10 rate your interest in engineering (1-not interested, 10 - highly interested) (Refer Appendix G)**

Appendix G show that 94% of students rated 6 and higher as their interest in engineering at the end of the project, as compared to around 83% at the beginning. The integrated project stimulated their interest in engineering and exposed them to different areas in engineering.

Table IIIC lists the students' prior experiences with inventions and design. Experience with inventions and design is considered an indicator of interest in engineering.

| IIIC. Have you invented something by yourself? | | | |
|---|---|---|---|
| Questionnaire# | Yes | No | Explain |
| I | 4 | 14 | I designed a house with 3 stories and I loved doing it.<br>I created a little device with pieces of wood and a bolt to crack nuts.<br>There's way too many things to name. I've been doing it since I can remember. My coolest one was a full sized, working hovercraft from my own design and manuals.<br>A model rocket in $4^{th}$ grade. |

**IIID. On the scale of 1-10 rate your interest in inventing something (Refer Appendix H)**

Appendix H show that 100% of students rated 6 and higher as their interest in inventing something at the end of the project, as compared to around 77% at the beginning.

Based on the above observations and the principles of physics, chemistry and mathematics that the students identified (Table IIA-IIF) for the project, we conclude that the exercise of designing and presenting projects, stimulated student interest in science and engineering.

**Case Studies**

Two case studies described below may be helpful to show how individuals improved as a result of their participation in the ESP. The case studies give a different perspective from all the data presented earlier. Case A below is a female student, while Case B is a male student. The responses from the questionnaire for the two cases below indicate that the students had a prior knowledge regarding what engineering is, but by the end of the program they got a better understanding regarding the mechanics involved in product design and the group activity involved. Students realized some of the positive and negative aspects involved in a group activity and adjustments needed for proper functioning of a group. The students had the opportunity to identify and implement some of the concepts they learned in the class into the actual product design. Thus they got better informed regarding different disciplines involved in engineering, which would certainly help them to select the career path in the near future. Details of the cases are presented in the tables below. Note that student responses from Questionnaire I were at the beginning of their design project and their responses from Questionnaire III were at the end of their project design experience.

1. **Describe in 3-4 sentences what engineering means to you.**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | Engineering means finding solutions for difficult problems. It means working together to discuss simple and efficient ways of problem solving. Engineering means thinking of crazy ideas and making them work. | Engineering to me is working together in groups and combining the best ideas to produce best working product |
| B | Engineering is the process of designing and creating new things. These things could be processes, structures, computers, toys or many other things. An important thing about engineering is that its not simple and narrow field, but rather a wide range of fields. | Engineering is the process of designing products and processes that will be used by others |

2. **One aspect of group work you like the most**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | Hearing the ideas of others and then collaborating the ideas to be productive | I like the aspect of getting very different ideas and making all of the ideas to combine into a working product in the end |
| B | There are interesting ideas and points of view | I liked the flow of ideas from different people |

3. **One aspect of group work you dislike the most**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | Disagreeing about what ideas are the best | I do not like the aspect of not agreeing on certain things |
| B | People want to do different things or distract the group | We had trouble getting everybody ready to work at the same time |

4. **Steps involved in designing a commercial product**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | First you must find out what your purpose is in designing this product. Then you must plan the procedure of designing a certain project. Finally you must try out your product and use trial and error to fix it | Plan how time will be spent. Brainstorming is important. Then you must analyze the brainstorming and see what ideas are best. Then you must construct and test your final design |
| B | One first identifies the problem to be solved. Then one brainstorms ideas for how to solve the problem. After that one evaluates those ideas to create a preliminary design, then one tests that design then repeats the process until one doesn't have any more time at which point one uses their best design | One must identify the problem to be solved, then brainstorm ideas for solving it. After brainstorming ideas can be evaluated. Finally, you create a design, test it, then design and test again ( and again and again) |

5. **Mention one principle from physics you might plan to use**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | The force of gravity that will prevent a baby from falling from a chair | F=ma, torque= Fd |
| B | Forces and force diagrams | calculations of force, Fg= mg (g=9.8m/$s^2$ on earth) |

6. **Mention one principle from chemistry you might plan to use**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | What are the materials made up of that we are using | |
| B | Material composition and strength | composition of materials: how strong are different materials |

7. **Mention one principle from mathematics you might plan to use**

| Case | Response<br>Questionnaire I | Response<br>Questionnaire III |
|---|---|---|
| A | The dimensions of a chair | finding the dimensions of wood and how much room we would need for a child |
| B | Pythagorean theorem | calculation of permissible size of flair using trigonometry |

8. **What field in engineering interests you the most?**

| Case | Questionnaire I | Questionnaire III | Please explain why (Questionnaire III) |
|---|---|---|---|
| A | Civil | Mechanical, Civil | Mechanical engineering is interesting to me because I realized from ESP that I like to figure out how things work and what the best way to make them is. Civil Engineering is interesting to me because I like drawing and design. I am also thinking of some kind of architecture. |
| B | Computer | Computer, Electrical, Environmental | I care deeply about conservation of the environment and sustainability. I also have a big interest in computers and electronics. |

**Future work (recommendation for ESP 2006)**

Based on the analysis and conclusions, the following recommendations would make ESP 2006 even more effective.

- The program needs to facilitate the group work more effectively to keep the students motivated. One of the ways would be to monitor, assess and reward individuals for their contributions for the design projects.
- The program should include projects which would involve all the students with equal work distribution. The lack of understanding regarding steps involved in product design indicated in Table IE by one of the students indicate that the project selected did not demand involvement of all the students.
- The program needs to put more emphasis on students' presentation skills for effective communication. Data on Table IIF indicates that the students became more aware, as they completed the program, of the skills they lack for effective presentation and demonstration of their projects.
- The program should select design projects that would incorporate principles from all the subjects including physics, chemistry and mathematics and be feasible in the short time provided. This would allow students to have a better appreciation of how these topics could be integrated into a single design project.

Based on our research, introducing real-life engineering design projects and integrating five courses into the Engineering Summer Program (ESP) for high school students has made a difference in student learning.

**Acknowledgement:** We would like to thank all the ESP instructors namely John Murphy (Introduction to Engineering), Christine Nicometo (Technical Communications ESP2004), Katie Gilbert (Technical Communications ESP2005), David Dueber (Mathematics), Oumar Kaba (Mathematics) and Thiagarajan Sivanadyan (Physics) for all their support for the ESP program. We would also like to thank Dr. Donald Gillian-Daniel and Dr. Aaron Brower who are faculty members affiliated with the DELTA program at UW-Madison, for the valuable discussions and insights. We appreciate the help extended by the College of Engineering and the CIRTL group at UW-Madison and would like thank them for their continued support.

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**Appendix A. Program Description (sent to students)**

**Engineering Summer Program (ESP**) June 16 - August 3

If you want an exciting career in which you can make your mark and set the pace for the future, engineering may be a great choice for you. The Engineering Summer Program (ESP) at the University of Wisconsin-Madison can help you prepare early for academic and professional success in engineering.

With the employment outlook for engineers brighter than ever, this is an especially exciting time to consider the many engineering career options available to you. Success, however, requires both knowledge of career options and strong skills and ability in math and science. ESP helps you learn about engineering career options while strengthening your skills and preparing you for the rigors of college life. The program covers most costs.

**The Program Design**

ESP is a seven-week residential summer program that gives high school students of color and women an opportunity to explore engineering careers while preparing for college-level study. ESP will provide you with an opportunity to take college-preparatory courses in math, science, and engineering. All ESP courses are taught in UW classrooms and laboratories. Professors and instructors selected to teach ESP courses are especially sensitive to the needs of high school students of color and women. While participating in ESP you will eat in an UW-Madison cafeteria and live in a residence hall on campus. Program counselors also will live in the dormitories, supervising students and advising them on academic and career options.

**Who Can Participate**

ESP is open to traditionally underrepresented groups (women; African Americans, Hispanic Americans; Native Americans; and South East Asian Americans) who are interested in pursuing a career in science and engineering. Students who are high school sophomores and juniors may apply. Participants must be U.S. citizens or permanent residents. You must have a minimum high school grade point average of 3.0, on a 4.0 scale, and currently be a high school sophomore or junior who will have completed at least one year each of algebra, geometry, and chemistry by June 2002.

**The Benefits of ESP**

Upon successful completion of the program: ESP students will receive a half (1/2) unit of high school credit towards their graduation. Past experience shows that students returning to high school after participating in ESP often excel in their remaining high school math and science courses, improving their grade point averages, and moving up in class rankings. Moreover, ESP helps students learn what is expected of them academically and socially during their college years, and how they can plan early for professional success later. Many students have been able to take more advanced high school courses during their senior years.

**A Curriculum Geared to Engineering**

During the summer program, participants will enroll in specially designed courses related to engineering, math, chemistry, computer science, and writing. After being admitted into ESP, students take placement exams administered by the UW to determine the most appropriate math course for them to take. Students participate in the following courses and seminars, depending on the outcome of their placement exams.

**Courses**

The courses offered at the ESP are as follows:
Introduction to Engineering – Designed to expose students to the various engineering disciplines through presentations, demonstrations and some hands-on activities.
Pre-Calculus – Designed to increase students' proficiency in algebra.
College Calculus – Emphasizes conceptual and computational features of calculus.
Physics – Designed to a foundation to future college courses in physics.
Chemistry – Introduces college-level chemistry, including the use of math as an integral tool.
Computer Science – Focuses on computer languages and functions. This course is designed to give students an introduction to computer science and computer engineering.
Technical Writing – Exposes students to written, oral and media communication focused on science and technical writing.

**Seminars & Field Trips**

Engineering Professional Development – Covers subjects such as time management, note taking, study skills, resume writing, and preparation for job interviews.
Industrial Seminars – Lectures given by professional engineers explaining the roles of engineers in engineering-related businesses and manufacturing.
Industrial Site Visits – Field trips help to demonstrate practical applications of engineering.

In addition to courses and seminars, each student has regular meetings with the program staff to evaluate academic progress and discuss areas for improvement.

**ESP Cost is Minimal**

The ESP participants are required to pay only a $50.00 registration fee. The program covers the cost of books, instructional materials, room and board, field trips, and other scheduled recreational activities. ESP participants may use University libraries, athletic facilities, and limited health services free-of-charge. ESP students are responsible for the cost of transportation to and from Madison and for personal spending money.

**Appendix B: Sample Budget**

| Summary | | |
|---|---|---|
| Total Allocated | 93,178.00 | 100.0% |
| Total Expended | 82,227.78 | 84.6% |
| Total Unused | 14,969.95 | 15.4% |

As of 10/06/04

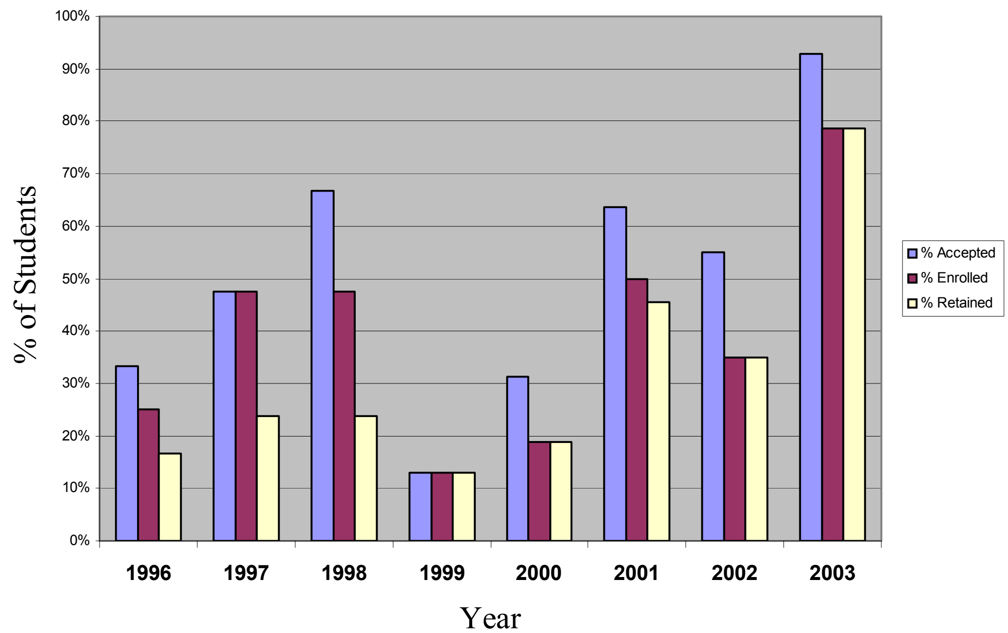
| | | |
|---|---|---|
| **Student Expenses** | | **$40,808.59** |
| Student Housing/Meals | 33,811.10 | |
| Student Supplies | 1,082.50 | |
| Student Insurance | 400.00 | |
| Social Activities | 3,162.99 | |
| Segregated Fees | 2,352.00 | |
| **Instructional Expenses** | | **$32,135.12** |
| Peer Counselors (all inclusive with fleet vehicle) | 9,205.00 | |
| TA Instructors | 15,876.97 | |
| Professor | 7,053.15 | |
| **Operational Expenses** | | **$10,934.07** |
| Project Assistant | 5,763.87 | |
| Opening & Closing Banquets | 1,616.60 | |
| Operating Supplies | 55.88 | |
| Guest Meals | 546.90 | |
| Photos | 1,124.27 | |
| Other Housing Fees | - | |
| Brochure Prntg/Mailing | 39.20 | |
| Misc Prntg/Dpl Fees | 33.00 | |
| Misc. Supplies | 309.35 | |
| Chemistry Labs | 350.00 | |
| Travel | 1,095.00 | |
| **MISC Expenses** | | **-$950.00** |
| Deposit from registration fees collected | (950.00) | |
| **TOTAL** | | **$82,927.78** |

Budgeted per Student $4,051.22
Spent per Student $3,605.56

Note: Contribution from Microsoft $700.00

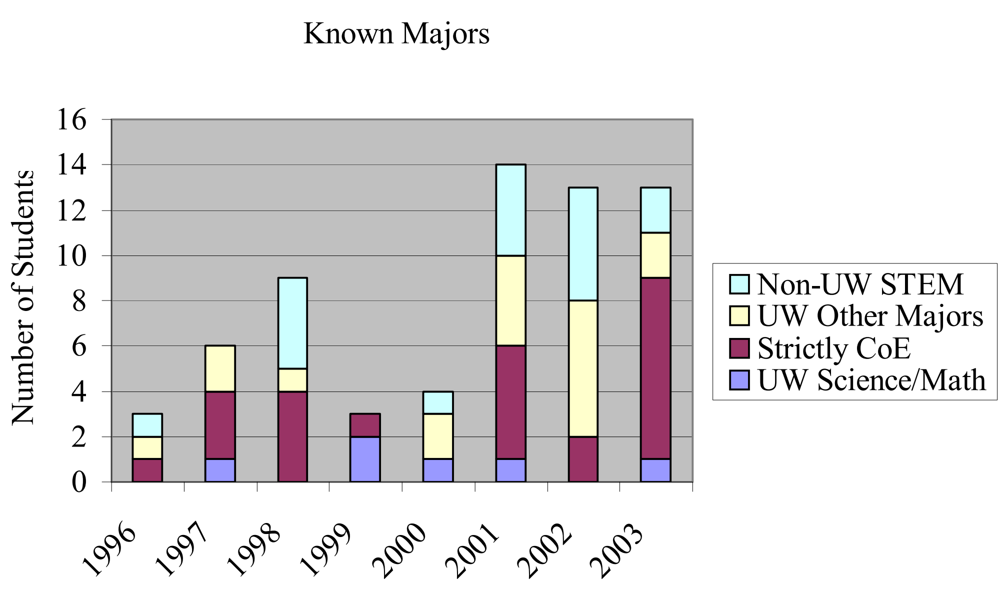
**Appendix C. Program Review**

This chart shows the number of ESP participants that apply and are accepted to the UW Madison, and are currently enrolled.

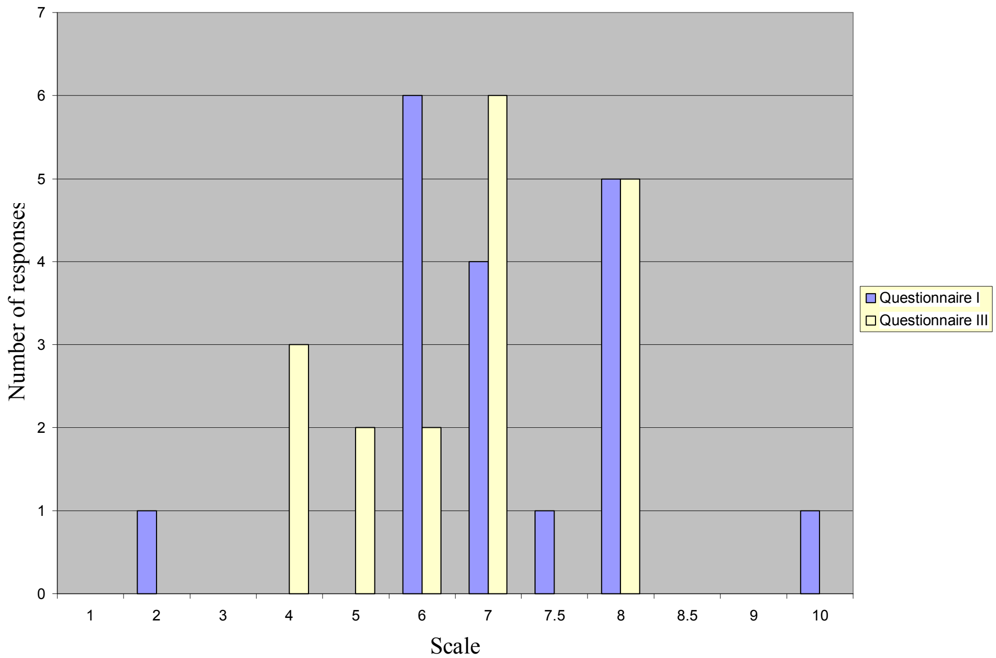



**Appendix D. Program Review by College Majors**

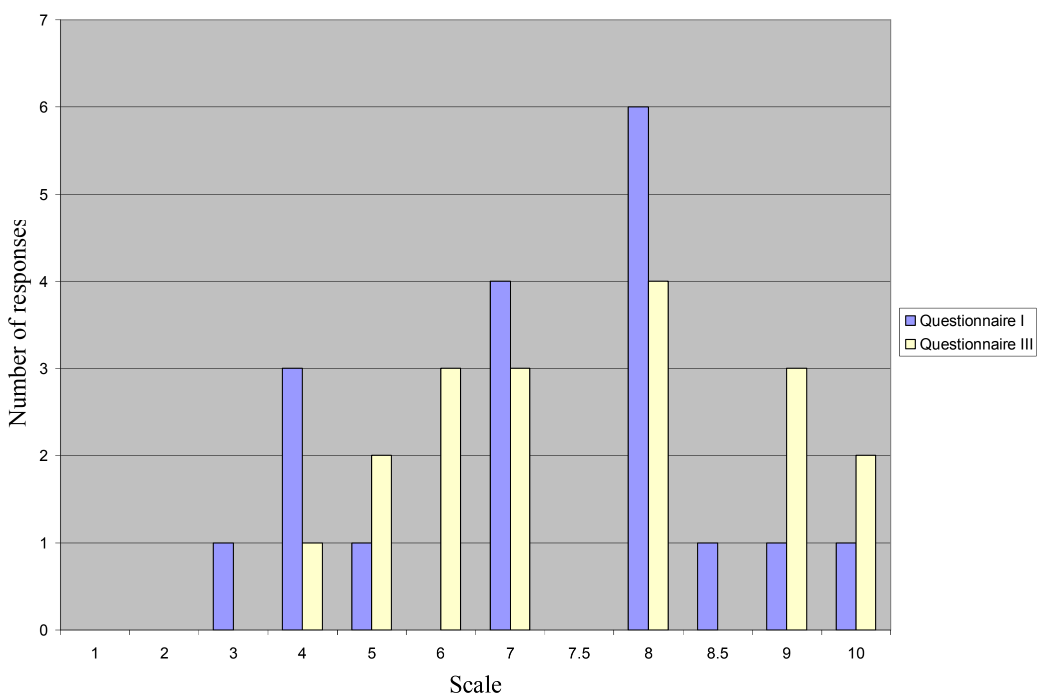
Since 2001 the College of Engineering has more carefully tracked the college attendance of students outside of the UW. Here we do not record humanities majors outside of the UW-Madison.



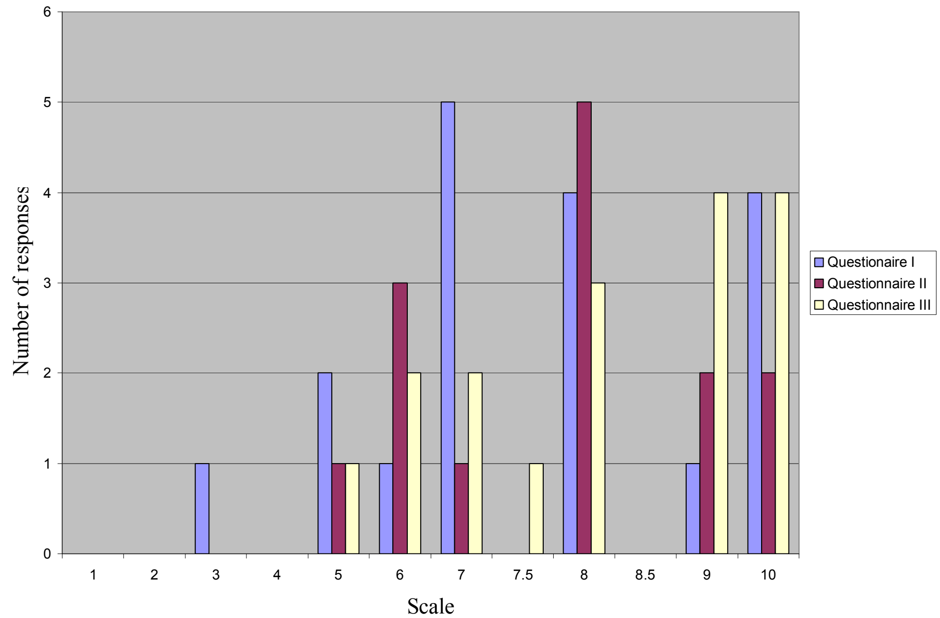
**Appendix E:** Chart describing on the scale of 1-10 rate what students think their presentation skills are (1-poor, 5-good, 10-excellent)




**Appendix F:** Chart describing on the scale of 1-10 rate what students think is their experience working in a group are (1-poor, 5-good, 10-excellent)



**Appendix G:** Chart describing on the scale of 1-10 rate of students think their interest in engineering (1-not interested, 5-kind-of interested 10-highly interested)




Note: Not all students responded for Questionnaire II.

**Appendix H:** Chart describing on the scale of 1-10 rate of students think their interest in inventing something (1-not interested, 5-kind-of interested 10-highly interested)