AC 2010-1795: UNDERGRADUATE INVOLVEMENT IN DEVELOPING K-12 HANDS-ON ACTIVITIES

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Abstract:

The School of Engineering takes a very active role in the K-12 outreach programs at Penn State Erie, The Behrend College (PSB). The school participates in several formal on-campus programs. Additionally, many faculty members go to local schools to work with students in their classrooms. The focus of the engineering outreach efforts is on hands-on activities. Many such activities are commercially available, and some of those are used at PSB, but most of the activities that are used are developed by individual faculty members in their particular areas of expertise. These include such activities as simple motors, bridge building, wind power, and many more.

As part of the effort to design these hands-on activities, an independent study course was offered in the spring of 2009 for Mechanical Engineering Technology (MET) students as a technical elective. The objective of the course was to design, build and test four hands-on activities to be used as part of the school’s K-12 outreach programs. Eight students signed up for the course. They were split into four teams of two students each working on separate projects. The general topics were pulley systems, vibrations, alternative energy and thermoelectric devices. Some of the projects were more successful than others, as might be expected. The overall outcome was a success and resulted in several hands-on activities that have been used for students in grades 1-12.

This paper begins with a brief overview of the outreach programs in the School of Engineering. The main topic of the paper is the independent study course. The course goals and general project requirements are included. Each of the four projects are discussed with an emphasis on the project goals, activities that were developed, success levels, and ongoing efforts to improve the activities that resulted from the course. The paper also includes a brief discussion of the implementations of the activities to date.

Introduction:

The National Science Board has predicted that the growth in demand for workers in science and engineering occupations will grow at twice the rate for all occupations over the next five years\(^1\). This does not even include other related fields which also attract many graduates from science and engineering programs. The National Center for Education Statistics projects a growth in overall undergraduate enrollment over the same time period to be about half of the rate of the demand for workers\(^2\). With this kind of demand, colleges and universities across the nation are looking at ways to increase enrollments in these fields. It all starts with science, technology, engineering and mathematics (STEM) outreach programs for K-12 students. It is important to build interest among students toward STEM disciplines so they will consider a higher education in those fields. The University of Texas, for example, has implemented their AIM project designed to help public schools with engineering and science training\(^3\). Iowa State University\(^4\) has developed an educational outreach center with several goals, including developing “learner-centered, hands-on, engineering activities with K-12 students”. Ryerson University in Toronto\(^5\)
has instituted a successful outreach program which was originally designed to target girls, but has been expanded to include all high school students. This is just a sampling of the large number of colleges and universities who are actively engaged in these kinds of outreach activities.

In addition to college and university initiatives there are a wide range of private efforts focused on improving STEM education in K-12 schools. Project Lead The Way partners with industry, universities and public schools to promote engineering in middle and high schools. IEEE has recognized the importance of motivating the teachers to improve STEM education, so they conduct seminars nationally to teach the teachers to use a wide range of hands on activities they have developed. Many others are doing similar things.

Faculty and administrators at PSB have recognized the need to improve their outreach activities. To this end an Engineering K-12 Outreach Lab has been established at the school. Faculty throughout the schools of engineering and science are increasing their volunteer efforts to not only provide quality hands-on activities for K-12 students, but also to work with middle school and high school teachers to motivate them to incorporate some of these activities in their classrooms. Many hands-on activities are needed to support these efforts. This paper gives a brief description of the on-going outreach activities at PSB and some background on what factors should be considered in developing a good activity. The main focus will be on the independent study course that was designed to get undergraduate MET students involved in creating some of the hands-on activities.

Overview of STEM Outreach at PSB:

At PSB there are several STEM outreach programs intended to make science and engineering activities available to kids of all ages. College for Kids, for example, is a summer enrichment program that started in 1993 which has one week sessions throughout the summer for ages 6-16. There are over 500 participants every summer. Activities are age group specific and are designed to be hands-on and fun for the kids. Another major program is Math Options Career Day now celebrating its 14th year. Close to 250 girls from over 40 regional middle schools visit the campus for a day and participate in three one hour hands-on sessions in math, science, technology and engineering. Over thirty sessions are offered including CSI, solar powered cars, zoo math and many others.

Minority College Experience / Women in Science and Engineering, now in its 22nd year, is a summer program for academically talented twelfth grade students. Students sign up for an eight week summer course for college credit. The program is completely free, including textbooks, lunch and transportation to and from the campus. By passing the course with a 3.0 or better grade a student receives guaranteed acceptance at PSB. 21st Century Kids provides hands-on workshops for middle school students in Erie and surrounding counties. Penn State Educational Partnership Program (PEPP) is a program for at risk students. Community volunteers, PSB student tutors and PSB staff work together to provide opportunities for middle and high school students to improve academic and leadership skills. PLASTCar is a unique, interdisciplinary, semester long program for sixth graders. A course in the Plastics Engineering Technology program partners with courses in Business and Psychology to work with sixth graders to design
and build small Matchbox® race cars. They work through the entire design process including concepts, computer modeling, prototyping, wind tunnel testing, final production and ultimately the races. Many other programs also use hands-on activities to support their efforts, such as Women in Engineering, Physics Day and Chemistry Day.

While these formal programs provide the backbone for the K-12 outreach activities at PSB, many of the faculty members in the School of Engineering and the School of Science are involved in smaller, less formal activities throughout the year. For example, one faculty member has a “bridge in a bag” activity which is taken into elementary through high school classrooms. All of the pieces needed to build an entire eight foot long bridge, which can easily support 1000 pounds, are brought into the classroom in an average sized duffle bag. The students get to build the bridge and learn a lot about bridge design and blueprint reading in the process. Many similar activities are done by other faculty members.

**Developing Appropriate Activities:**

Mazur, et al have taken a look at the effectiveness of in-class demonstrations. They have concluded that students who only observe demonstrations in a classroom tend not to learn any better than students who do not observe the demonstrations. However, they found that learning is enhanced by getting the students actively involved in the activities. Westrom points out that many middle and high school students feel that “science and mathematics are hard and boring and not fun and exciting”. One of the key goals of a K-12 outreach activity must be to keep the students actively engaged. This leads to the need to develop age appropriate hands-on activities for the students.

If K-12 teachers are going to “buy in” to any activities they must be aligned with educational standards. Several teachers at a recent IEEE “Train the Trainer” workshop stressed that their time is limited and they probably would not have the time to deal with activities outside the scope of the educational standards. Several other factors can make activities attractive to K-12 teachers. For example, activities should be rich in terms of educational potential and teaching points. They should be tiered to assure that all of the students in a classroom can participate in a meaningful way. Extension activities need to be provided to assure students have something to do if they finish the activity early. Also, training or other background information should be available for the teachers so they fully understand the activity.

While these are important factors for incorporating hands-on STEM activities into a K-12 classroom, another goal exists for these activities that does not involve classroom participation. Some activities are not necessarily designed to teach, but more to develop interest in STEM fields among K-12 students. These activities should be hands-on, fun and age appropriate. Getting the students excited about engineering, science and math is the goal. At PSB there is a need for many such activities to support on-campus programs such as Math Options Career Day and Women in Engineering. The activities that were developed as part of the independent study course described in this paper are part of that effort.
Getting Undergraduates Involved:

One way to help reduce the burden on faculty to generate all of the activities that are needed to support the outreach efforts is to get undergraduates involved. There are many examples of this across the country. At Michigan State senior projects were used to develop a variety of demonstrations for use in local elementary schools. Among their projects were a wind power demonstrator, a solar heated worm compost bin and a global warming demonstrator. A group of professors and undergraduate students from the University of Cincinnati, University of North Dakota and University of Oklahoma partnered to develop demonstrations to teach about seismic design. The PLASTCar program at PSB has Plastics Engineering Technology, Psychology and Business undergraduates involved with sixth graders to design plastic race cars. Mechanical Engineering Technology students were also involved during the first year of the PLASTCar program to design and build the race track for the cars (Figure 1).

The independent study course described in the rest of this paper was another attempt to get undergraduate students involved in the K-12 outreach programs at PSB.

Independent Study Course:

During the spring 2009 semester at PSB, an independent study course was offered to Mechanical Engineering Technology juniors and seniors as a technical elective. The goal of the course was to develop a group of hands-on activities to use as part of the PSB K-12 outreach programs. There were six main objectives for the course:

1. Layout a project from design to finished product, which includes items such as a Gantt chart, storyboard, and prototype.
2. Complete calculations and analysis where appropriate.
3. Create a set of working drawings for the project. This includes creating detail and assembly drawings and the parts lists necessary to coordinate the drawings.
4. Manufacture parts to specifications.
5. Create supporting material, such as lesson plans, posters, MS PowerPoint, videos, and instructions that explain the project from the engineering principles behind the project through practical applications.
6. Present in a professional manner according to the venue (open house, conference, etc.)

The class met one hour a week for project update reports. In addition to the weekly meetings the students were required to:

1. Present a mid-semester oral presentation to the MET faculty.
2. Create posters supporting their project.
3. Display their posters and completed open house projects at a school open house near the end of the semester.
4. Conduct a 50 minute hands-on activity with high school students using the materials developed during the semester.

5. Present an end of semester oral presentation at the Sigma Xi undergraduate research conference held at PSB.

Eight students signed up for the course. It was decided to split the class into four groups of two each to work on separate projects. The project had three distinctly separate parts for the students to complete. The first was an interactive demonstration to be used primarily at open houses or similar activities. Next was a fifty minute to one hour hands-on activity to be used mainly for on-campus K-12 outreach activities. Finally, each group was required to create a poster to pull everything together. The four projects that were selected were alternative energy, pulleys, vibrations and thermoelectric coolers.

**Alternative Energy Project:**

The alternative energy project team decided to build a human powered generator using a bicycle for the interactive demonstration. The bicycle is connected to a small generator through a belt around the back rim. The generator supplies power to the motor of a leaf blower. A clear acrylic tube is connected to the outlet of the leaf blower. The leaf blower drives a ball up the tube. The distance the ball travels depends on the amount of power generated by the rider. The tube is labeled to indicate common appliances that can be powered at various levels up the tube. Figures 2 and 3 show the bicycle and a high school student from the PSB PEPP program trying it out.

The students working on this project were somewhat challenged while trying to design the ball in the tube feature. A free-body diagram of the ball reveals that the ball will go directly to the top once enough power is generated to lift it off the blower outlet. Their solution was a series of slots along the length of the tube which allowed air to escape as the ball rose. The slots create a non-linear relationship between the power generated and the height of the ball. This allows the smaller children to successfully lift the ball while also challenging the best riders to reach the top and hold it there. To reach the top the rider has to generate close to 350 watts.
For the hands-on exercise the students selected solar cars. Solar car kits were purchased from Pitsco Education\textsuperscript{16}. Figure 4 shows a picture of the finished car. The car comes with double sided tape to mount the motor, but was modified to use magnets. This makes it easier to disassemble and re-use. The students are given a set of assembly instructions based on the age group. For younger kids the instructions are step-by-step pictures of the assembly process. Middle school age students receive a written set of instructions and high school students get minimal verbal instructions. The instructions using the pictures have been tested with students as young as first grade with good success. Figure 5 shows a group of Tiger Scouts assembling the cars.

Once the cars are assembled they need to be tested and debugged. Students test their cars by shining a trouble light on the solar panel. Trouble lights are used to replace the sun so that we were not dependent on the weather or the time of the day. There are several common problems. Table 1 shows a brief trouble shooting guide. Once the cars are working properly the older students cars are raced in a double elimination format. This assures that every group gets at least two chances to race their car. Figure 6 shows a high school student racing her car. A banquet table is used as the race track.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Likely cause</th>
<th>Possible solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor will not turn</td>
<td>The gears are meshed too tightly.</td>
<td>Adjust the gears</td>
</tr>
<tr>
<td></td>
<td>The electrical leads are rubbing on the wheels</td>
<td>Reposition the leads</td>
</tr>
<tr>
<td></td>
<td>Bad motor</td>
<td>Replace the motor</td>
</tr>
<tr>
<td></td>
<td>Bad solar panel</td>
<td>Replace the solar panel</td>
</tr>
<tr>
<td>Wheels turn backwards</td>
<td>The electrical leads are connected backwards</td>
<td>Switch the electrical leads</td>
</tr>
<tr>
<td>Motor turns but the wheels do not turn</td>
<td>Gears are not meshed</td>
<td>Adjust the gears</td>
</tr>
</tbody>
</table>

Table 1 Troubleshooting Guide
The solar car exercise has been used with every age group from first grade through high school. Several potential improvements have been identified and will be incorporated in the future. First, the most difficult part of the assembly is mounting the motor in the correct location. Currently there is a magnet on both the motor mount and on the car body. The polarity of the magnets create some positions that will not work. One solution being considered is to eliminate one of the magnets and replace it with a small piece of steel. This should provide an easier method for positioning the motor. The next issue is the mounting of the solar panel itself. Currently it is held down with two small pieces of modeling clay. The clay does not seem pliable enough to be reliable and solar panels tend to move around or fall off. Possible solutions for this problem include softer putty or Velcro®.

Notice in Figure 6 that the girl is trying to hold the light parallel to the solar panel during her race. This generates the maximum amount of power which results in the most speed. A final enhancement to this exercise will be to add a solar panel test before actually building the cars. Students will be able to test the power generated as a function of the angle between the light and the panel. They can then plot a curve to clearly show that the most power is generated when the light is parallel to the panel. Hopefully they will transfer this information to practical use in the races.

Pulley Project:

The purpose of the pulley project is to investigate mechanical advantage as it relates to pulleys. The interactive demonstration has two parts, a modified commercial pulley demonstration unit from PASCO®¹⁷, Figure 7, which uses small weights and a homemade pulley system, Figure 8, using two 50 pound weights.

The commercial unit has four pulley systems with different mechanical advantages. It is especially useful for demonstrating the relationship between the force needed to lift the weight and the distance the force has to move. Four modifications have been made to the unit. First,
extra pulleys and a pulley support bracket were added at the bottom to keep all of the pull rings at the same level. Secondly, bungee cords were added to hold the weights in place when the unit is moved. Next, the cord that is provided with the unit for stringing the pulleys was replaced with coated aviation cable because it is more durable and less prone to tangling. With those three changes the unit was used at an open house where another weakness surfaced. It was very easy to lift the weights too high causing them to hit the top pulley and fall off the hanger. The fourth modification was to add cables to limit the travel of the weights, which solved the problem.

The system shown in Figure 8 is comprised of a heavy duty steel saw horse for support, two pulley systems with different mechanical advantages and two 50 pound weights. This demonstrates very clearly how pulleys can greatly reduce the force needed to lift a heavy weight. After initial trials with this device it became obvious that the weights posed a danger if they should fall on somebody’s hand. Guards were installed to protect against this happening.

Figure 9 shows two high school students working with the hands-on exercise associated with the pulley project. Students are given a stand, weights and a set of pulleys. They build a variety of systems and determine the mechanical advantage of each system. They test the relationship between force and the distance the force has to move, and try to make sense of that relationship relative to the mechanical advantage. After they learn about how pulleys can multiply forces they have an opportunity to try a real system attached to a pallet loaded with cinder blocks. Figure 10 shows a group of middle school girls trying to slide the pallet along the floor of the parking ramp on the PSB campus. They discover that it is an easy task with the assistance of the pulley system.

There are some improvements that can be made to this exercise. The pulleys and cables used for the hands-on activity are somewhat difficult to work with. One improvement might be to replace those components with others that are easier to use. Going beyond the hardware, the procedures need to be examined. The students work in teams of two. Several of the teams that were set up when this exercise was first used were made up of one boy and one girl. It was observed that the boys did all of the building and the girls sat back and watched. The next time this activity was used was with a group of middle school girls only, so gender was not an issue. This is something that should, at a minimum, be monitored to assure that both boys and girls participate equally to get the maximum benefit from the exercise.
Vibration Project:

The demonstration that was designed for the vibration project was a small shaker table with three bobbleheads mounted to the top. A function generator connected through an amplifier drives the shaker. Frequencies can be slowly increased.

Students expect the heads on the dolls to shake when the unit is turned on, and to continue to shake as the frequency is increased. Actually, the different bobblehead figures have different resonant frequencies and shake violently at different times as the frequency input is increased. Children are quite surprised to see that the figures stop shaking once they get above their natural frequency. Comments from students watching the demonstration included “why are they shaking separately?” and “how did you do that?”.

Figure 11 shows a solid model of the shaker table and Figure 12 shows the complete set-up. The set-up includes the shaker table with the bobbleheads mounted to the top, function generator, amplifier and an oscilloscope used to display the input. Short videos showing resonance, such as the Tacoma Narrows Bridge (Galloping Gertie), are also shown.

The hands-on activity was based on an earthquake kit purchased from Pitsco Education. It includes a low frequency shaker table and materials to build balsa wood towers. After a tower is built weights can be added to each floor of the tower. The entire assembly is mounted to the table and shaken at various frequencies until it collapses. This activity turned out to have problems even though a commercial product was used. The activities that were suggested by the manufacturer are designed to be carried out over several class periods, but most of our hands-on sessions are about an hour long. The glue that comes with the kit takes more than an hour to dry and hot glue is not recommended by the manufacturer due to its flexibility. The solution was to pre-build the towers and let the students decide where to mount the weights they were given. Figure 13 shows students working on mounting the weights.

Several issues remain to be addressed with the vibration project. The shaker table used for the bobblehead demonstration tends to rattle against the guide rods. A temporary fix using tape to cushion the rattles was used, but a more permanent solution would be desirable. The biggest issue is with the hands-on portion. Pre-building the towers takes a lot of the “hands-on” out of the exercise. Work is currently being done to try to find a method of building and testing the tower within a one hour time period. The main focus is on alternative building materials for the towers. Therefore, one of the criteria for finding a new building material is that the tower should break when it hits resonance. It is interesting for
the students to see the tower shake violently at resonance, but it is much more dramatic if the tower actually breaks.

**Thermoelectric Cooler Project:**

The hands-on activity involves building a thermoelectric cooler/heater similar to commercial units that are available. Figure 14 shows a commercial cooler and a prototype of the unit that will be built during the activity. The heart of the cooler is a Peltier device. A DC voltage is applied across the leads of the device causing one side to get hot and the other side to get cold. Reversing the leads switches the hot and cold sides, so the unit can be used as either a cooler, or as a warm space.

As is often the case in any course, not every student is successful. Unfortunately, this project was not completed. However, work study students are currently working on this project.

For the activity students will be given a kit containing all the pieces that are needed to build the cooler and a set of assembly instructions. Groups of two to three students will assemble the coolers. After the coolers are assembled the air temperature will be tested to see how well they cool. One of the key factors determining how cold the cooler will get is the heatsink, which can be seen on top of the prototype in Figure 14. Each group will have a different heatsink so the students can see the difference in cooling capabilities. The power source is a commercial power supply which is repackaged for ease of use. All of the wires will be color coded so that it will be very easy for the students to make the connections. Once the units are built they will be connected to a data collection system to measure how cold the cooling plate inside the cooler gets.

This project is nearing completion. A prototype power supply has been made and tested. Several more are currently being assembled. Three other tasks have to be completed before the activity is ready for use. First, a lesson plan needs to be developed. One of the open questions that needs to be answered before the lesson plan can be completed is how long it takes for the cooler temperature to drop. If it takes excessive time for this to happen it will probably be better to measure the surface temperature of the cooling plate than the actual air temperature inside the cooler. Secondly, detailed assembly instructions need to be written. These will include both written instructions and step-by-step diagrams. Finally, the parts kits need to be assembled. There will be enough kits to build five coolers.

One thing that remains to be tested is the effectiveness of thermal grease compared to thermal interface pads. The grease is easier to use in terms of assuring the contact surfaces in the heat transfer path are well seated. On the other hand, thermal pads are much less messy for the students to use. Prototype testing will determine which material to use.
Posters:

Each of the teams was required to create a poster to highlight their project. The posters all had a common layout format. Figure 15 shows the poster that was made for the pulley project. The left panel describes the interactive display. It includes information about what it is and how to use it. The right panel shows basic information about the underlying theory behind the display. Finally, the center panel shows several real life applications, in this case for pulley systems.

![Pulley Project poster](image)

**Figure 15** Pulley Project poster.

Conclusions and Future Work:

At PSB there is a large and growing need for hands-on activities to use for all of the STEM outreach programs. Often they are developed by individual faculty members, but time restraints often limits what the faculty can do. To help in this effort the Mechanical Engineering Technology program offered an independent study course to get undergraduate students involved in developing some of these activities. Four projects were attempted and three were successful. The fourth is still under development.
Most of these activities have been successfully implemented several times for a wide range of age groups. Table 2 shows a brief summary of where they have been used. The solar cars and the bicycle are listed separately even though they are both part of the same project because they can easily be used as individual activities.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Program</th>
<th>Age Group</th>
</tr>
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<tbody>
<tr>
<td>Pulley project</td>
<td>Open House</td>
<td>High school</td>
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<td></td>
<td>Math Options Career Day</td>
<td>Middle school girls</td>
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<td></td>
<td>PEPP</td>
<td>High school</td>
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<tr>
<td></td>
<td>Tiger Scouts</td>
<td>First grade</td>
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<td>Vibration</td>
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<td>High school</td>
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<td>project</td>
<td>Math Options Career Day</td>
<td>Middle school girls</td>
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<td></td>
<td>PEPP</td>
<td>High school</td>
</tr>
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<td>Solar car</td>
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<tr>
<td>project</td>
<td>Math Options Career Day</td>
<td>Middle school girls</td>
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<td></td>
<td>PEPP</td>
<td>High school, middle school</td>
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<td></td>
<td>Tiger Scouts</td>
<td>First grade</td>
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<tr>
<td></td>
<td>Harbor Creek School District</td>
<td>Sixth grade</td>
</tr>
<tr>
<td></td>
<td>Warren Forest Higher Ed. Council</td>
<td>Fourth – sixth grade</td>
</tr>
<tr>
<td>Bicycle project</td>
<td>Open House</td>
<td>High school</td>
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<td></td>
<td>Math Options Career Day</td>
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<td></td>
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<td>High school</td>
</tr>
<tr>
<td></td>
<td>PA Industry Club Expo</td>
<td>Middle school</td>
</tr>
<tr>
<td>Cooler project</td>
<td>Still under development</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Activities Used

The main focus of this course was to involve the undergraduate students in developing these hands-on activities for K-12 outreach. Since then other benefits have come from this course. There is now a dedicated Engineering K-12 Outreach Laboratory (Figure 16) in our School of Engineering building. This provides us with an on-campus location where we can host groups of scouts, individuals and schools interested in STEM fields. This course was instrumental in starting a K-12 STEM outreach “library” of hands-on activities, which can be used on- or off-site.

Practicing engineers from the area are also excited with our K-12 STEM library. Many have volunteered to host their own workshops at events such as Women in Engineering and Math Options Career Day. However, most were uncomfortable with developing the activities. This library has allowed them to select an activity they are interested in, with minimal preparation on their side. Because of this more engineers are volunteering. It is truly a win-win for all involved.
Course assessment was also done with the undergraduate students to get their feedback regarding the course and the process. One student wrote: “This (course) very accurately portrays industry because as engineers we most likely be working on multiple projects at once.” Another student is quoted as saying: “other strengths were project management skills and relating to real life industry.” Faculty found that students were “surprised the amount of time and effort” it took in developing these activities.

Individual students and student groups are now seeking out faculty to get involved in these programs. Our Society of Women Engineers student chapter hosts Girl Scout Saturdays and student mentors are now involved in a new initiative by 4-H to start FIRST Robotics clubs in the area.

Five students recently submitted a summer undergraduate research proposal to not only finish and enhance the projects described in this paper but to work on other projects. The grant was awarded and the students will present their results at the 2011 Penn State Behrend-Sigma Xi Undergraduate Research and Creative Accomplishment Conference.

Overall, the independent study course proved to be a success. The course will be offered in the future and expanded to be multidisciplinary so that more engineering students can be involved and more engineering fields can be incorporated.
References:

17. http://www.pasco.com