AC 2010-561: HIGH SCHOOL ENTERPRISE: INTRODUCING ENGINEERING DESIGN IN A HIGH SCHOOL TEAM ENVIRONMENT

Douglas Oppliger, Michigan Technological University

Douglas Oppliger is a professional engineer and a lecturer in the Engineering Fundamentals department at Michigan Technological University. He is the director of the High School Enterprise program which has a mission to increase the numbers of students pursuing post-secondary degrees and careers in STEM fields. This work is the latest in Mr. Oppliger's long history of working in K-12 math and science. For the past 10 years he has developed and taught first-year engineering courses at the University and actively worked with high school students and teachers to increase and enhance engineering content in K-12 education. In 2004 Mr. Oppliger was awarded the Distinguished Faculty Award for Service honoring this outreach work. Before coming to Michigan Tech, Mr. Oppliger taught math and science at the secondary level for 11 years. Before that, he worked for 5 years as a project engineer in the marine construction industry.

Jean Kampe, Michigan Technological University

High School Enterprise: Introducing Engineering Design in a High School Team Environment

Abstract

In efforts to promote interest in engineering careers among secondary students, across the country there are several current initiatives intended to introduce engineering concepts at pre-college levels. There are basically three approaches in use: teach the concepts in a course dedicated to engineering, blend them into traditional courses such as math and science, or expose students to engineering in a project work environment. For concepts such as engineering design and project management, the project-based approach may be best. High School Enterprise (HSE) offers a project-based learning environment well suited to the introduction of these concepts. HSE is an extra- or in-curricular school activity where students from grades 9-12 engage in authentic, inquiry-based STEM (science, technology, engineering, and math) learning. Students participate on teams organized as virtual companies that develop products or services. Each year, there is a capstone event where secondary student teams gather on a university campus to present their project work alongside college teams to an audience of university faculty and students and industry representatives. The overarching goal of HSE is to seed and cultivate what will become a world-class and broadly inclusive science and technology workforce. Due to the long-term nature of the projects, there are many opportunities to introduce, and then spend significant time on, the engineering design process. To introduce engineering design concepts into this program, the topic was presented to teachers during a week-long workshop in the summers of 2008 and 2009. In 2008, the presentation was of a general nature and intended as a very basic introduction, while in 2009, a more extensive unit was presented encompassing both design and project management. This paper provides information on the current efforts to introduce engineering topics at the high school level and where HSE fits into this landscape. It describes the High School Enterprise program and how secondary students and teachers are exposed to engineering design. Some examples of student-project work from the 2008/2009 academic year that convey how students engage in the design process are included. Finally, the lessons learned to-date and how those lessons are helping to shape plans for future development and assessment are discussed.

The National Landscape of High School Engineering

Until just a few years ago, there were very few high schools that had any sort of engineering curriculum other than a small selection of graphics courses such as drafting and computer aided drafting. As of late, there has been a push to get more engineering content into high school curriculums. Today several state education standards address engineering to some degree, but there is considerable variation among those state standards, and the national effort to introduce such standards is still in its infancy. Indeed, the National Academy of Engineering is currently conducting a study (due out in March 2010) on K-12 engineering education standards. The Academy states: "The goal of this exploratory project is to assess the potential value and feasibility of developing and implementing content standards for engineering education in K-12." [1]

Even without widely accepted education standards, the importance of engineering has been recognized in many school districts. Many high schools are now offering curriculum choices in engineering and a few schools, many of them charter schools, center their entire curriculum on engineering or on science and engineering.[2] These schools use curricular material that has been purchased, or sometimes developed in-house to meet their needs. There are several pre-packaged engineering curricula available to high schools. Two well-known efforts are Project Lead the Way (PLTW - 2000 schools in 2009) and the Infinity Project (about 400 schools in 2009). These are both designed to be taught in a traditional classroom setting during the regular school day. They provide the teacher training and curriculum materials so schools can teach the program courses in a systematic and consistent manner. School districts that purchase these packages also bear the costs of required equipment and teacher training. Engineering Design is a separate curricular piece in both of these examples and is taught in a traditional classroom setting.[3,4]

In addition to these in-curricular programs, there are several extra-curricular programs which provide activities and/or competitions that deliver engineering or STEM content to high school students. The most visible of these are FIRST Robotics (1800 teams in 2010) and Science Olympiad (5700 schools in 2010).[5,6] There are also many college/university outreach programs in which area high school students participate in competitions, activities, sessions, or camps held on the campus of the college or university. The durations of these programs vary from an afternoon to weeks. And, while they may offer opportunities for students to learn about engineering design, whether or not this happens probably depends on the individuals leading these groups (mentors and/or teachers) and on the time available to do so.

Finally, there are several efforts sponsored by professional societies and other groups aimed at a high school audience. A sampling of these initiatives include ASEE's "Engineering Go For It!" (eGFI) publication and website. The eGFI website contains links for K-12 teachers interested in teaching engineering concepts that access activities and lesson plans from several sources.[7] Besides ASEE, almost every engineering professional society (IEEE, ASME, and ASCE are some notable examples) dedicates web space to a K-12 audience. These efforts, however, require that individual teachers take the initiative to access the resource and then implement the learning activity on their own.

To put the participation numbers given for these programs in some perspective, consider that there are about 27,000 secondary schools in the United States alone (including public, private, and charter institutes).[8] Given this, there are likely many, many schools that the STEM initiatives listed above have not benefitted. So, there remains a great need to increase and to diversify the venues for bringing engineering content to secondary students and thusly, it is hoped, to expand the pool of degree-seeking STEM majors in higher education.

High School Enterprise – how it fits into the landscape

High School Enterprise (HSE) has a mission similar to those programs presented above. It is a program designed to interest more students in STEM careers, particularly engineering. However, HSE is different from other programs in several significant ways. It is project based, but instead of specifying a particular project, student teams develop their own project ideas. Any project that has a STEM focus fits into the HSE model. In cases where HSE is an extracurricular program, teacher-coaches are paid comparably to athletic coaches. HSE projects are long-term, at least one school-year or longer. HSE teams are closely linked to a university partner and the secondary students visit the university campus each spring to display and present their project work. Another distinguishing feature of HSE is that it is designed to fit into (or along with) any high school. It works just as well in a charter school specializing in math and science as it does in an inner city school with a traditional course selection. This allows students with diverse interests to participate and offers the chance of introducing students who may never have considered engineering (or STEM) as a college or career choice. In fact, HSE has even engaged students from two alternative high schools.

The nature of the HSE model presents a unique opportunity to introduce engineering design to high school students. Of course, there are other ways in which students could be introduced to this concept. Indeed, Project Lead the Way offers an entire 9th grade course entitled "Introduction to Engineering Design." Nevertheless, HSE has features to deliver engineering design concepts to students whether or not they are getting any sort of engineering instruction in their regular school day. These program features are threefold: 1) the long term nature of the project, which gives students the opportunity to become familiar with the iterative nature of the design process(compare short projects which may give a hint at how the process works but rarely allow the "engineers" time to meaningfully cycle through the process); 2) the presence of a "coach" who is familiar with the design process and can help the students see where they are in the process and help with the cycling back when needed; and 3) the use of mentors from both industry and academia who help teams with their projects and can present the subject of design from a perspective much different from that of a classroom teacher.

Overview and History of HSE

High School Enterprise (HSE) is an extra- or in-curricular school program in which students from grades 9-12 engage in active, applied STEM learning. Students participate on teams organized as "virtual companies" that develop products or services as they engage in long-term projects with a STEM focus. HSE team projects are STEM-based but can involve students from all backgrounds and with a variety of interests. Students do not need have to have previous credentials (e.g., completed algebra) in order to contribute to the team in a significant way. HSE teams are coached by specially-trained high school STEM faculty called "teacher-coaches." Teams have access to real-world expertise and mentoring from professionals in academia and industry. HSE teams write business plans, solve real-world problems, perform testing and analyses, build prototypes, manufacture parts, operate within budgets, and manage their projects. Each spring, HSE teams showcase their work alongside college students at the University's Undergraduate Expo. At the conclusion of their HSE experiences, it is expected that the students will demonstrate proficiency in applied workforce skills, they will be more disposed to enter STEM careers, and they will be prepared to undertake the training and education needed to enter those careers.

HSE is modeled after Michigan Technological University's highly successful and nationally acclaimed undergraduate Enterprise program. The Enterprise program was founded on the proposition that the integration of active, applied learning into the undergraduate engineering curriculum would result in greater retention and graduation rates among undergraduate engineering students. Enterprise, which started in 2000 as a pilot program funded by NSF, has succeeded beyond expectations and has proved to be a sound investment. It is now a self-sustaining program that attracts engineering and other STEM-bound students to the University, keeps them, and makes them more marketable to employers when they graduate. [9,10]

In early 2006, representatives from the University, the local Intermediate School District, and local industry formed a commission to begin investigating ways to strengthen K-12 linkages to higher education and industry. This new commission has three charges: help strengthen the high school curricula to prepare more students for higher education and STEM careers, extend the excitement generated by the highly successful University Enterprise program into the K-12 system, and create a culture of 21st century entrepreneurship among high school students. Based on its positive experience with undergraduate Enterprise, the University agreed to fund a small, one-year pilot High School Enterprise program in three Michigan high schools for the 2007/08 school year.

Three diverse Michigan high schools and teachers were recruited to establish HSE teams and provide in-house teacher-coaches. During the summer of 2007, an initial workshop was held with several K-12 teachers to design the HSE program and present some basic engineering and business concepts. Three of these teachers went on to start teams at their schools. The HSE program director worked with these teams through the 2007/08 academic year to select projects, assist teams in establishing university partnerships, and advise and monitor the teams during the first pilot year. The three pilot teams – from Cass Tech in Detroit, Calumet High School in Michigan's Upper Peninsula, and Utica High School, a suburban Detroit area school – presented their work at the University Undergraduate Expo in April 2008.

Based on promising results from this effort, High School Enterprise has received two National Science Foundation awards to expand and assess outcomes of the High School Enterprise program: a $100,000 one-year grant under NSF's Innovations in Engineering Education, Curriculum, and Infrastructure (IEECI), and a $1.5 million, three-year award from the NSF Innovative Technology Experiences for Students and Teachers (ITEST) program began in December 2008. Using these two awards along with significant funding from the University and industry sources, we lengthened the pilot effort to five years and added more schools. We are now in Year 3 of this five-year pilot which will end in spring 2012.

Current Status of the HSE Program

Under the IEECI grant, the HSE program expanded to include five schools during the 2008/09 school year. ITEST funding allowed HSE to expand further. As of December 2009, there were ten HSE schools in Michigan, one in Georgia, and one in Puerto Rico. These schools include rural, suburban, and inner city schools. They are demographically diverse, enrolling students from all income levels, first generation college students, and high numbers of students from ethnic groups that are traditionally underrepresented in engineering. There are approximately 200 students in the program with 63% male and 37% female. Minority students make up 41% of the group with 24% African American, 13% Hispanic (this includes the team from Puerto Rico made up of 18 Hispanic students), and 4% other non-white minority. Table 1 presents profiles of the schools currently hosting HSE teams.

Table 1. Host school profiles for 2009/10 HSE teams.

High School and Location	Rural	Urban	Low Income	High Minority	At Risk
BRIDGE Alternative H.S. Hancock, MI	X		X		X
Horizons Alternative H.S. Calumet, MI	X		X		X
Hancock Central H.S., Hancock, MI	X		X		
Chassell H.S., Chassell, MI	X		X		
Traverse City Central H.S., Traverse City, MI					
Arthur Hill H.S., Saginaw, MI		X	X	X	X
Utica Community Schools, Utica, MI					
Cass Tech H.S., Detroit, MI		X	X	X	X
Melvindale H.S., Melvindale, MI		X	X	X	X
Detroit Inst. of Technology @ Cody H.S.		X	X	X	X
Tech High, Atlanta, GA		X	X	X	X
Manuel Toro H.S., Caguas, Puerto Rico		X	X	X	X

To provide additional support to these teams, the program has united a strongly committed set of partners that include three universities, the American Society of Mechanical Engineers (ASME), and several other industry, government, and foundation sponsors. HSE program assessment is led by an external team from the Science and Mathematics Program Improvement (SAMPI) Center at Western Michigan University.

The HSE Team and its Partners

HSE teams share these common features:

- HSE teams participate in virtual companies that develop products or services. The teams continue operations from year-to-year with some students leaving (e.g., graduation) and joining (e.g., matriculation) the team each year. Each team receives a pre-determined annual amount of money for project materials and supplies. Team members must develop and implement their own project plans and budgets.
- Team projects must have a STEM focus and teams are coached by specially-trained high school STEM teachers. These “teacher-coaches” receive a stipend each year on par with that of a high school athletic coach.
- In addition to their project work, students also receive some specialized HSE training which can include topics in applied workforce skills such as leadership, communication, entrepreneurship, and ethics, and does include basic engineering fundamentals such as the design process and project management.
- Team members make formal presentations at undergraduate research expositions, and they conduct project-based interactive sessions at middle and elementary schools within their local school districts. Using these latter activities as a starting point, the Enterprise model is being introduced into K-8 education.

- An HSE team operates within a partnership that includes the team's home high school, a university partner such as a student professional society group, and industry and community sponsors and mentors.
- Each HSE school will establish a set of community partners, as shown in the HSE operating model (see Figure 1), who will help sustain and grow the program. Partners can also serve as mentors and advisors to teams. Community partners may include large corporate sponsors, foundations, small and regional corporations, and academic booster clubs led by school and/or university alumni in the local community.

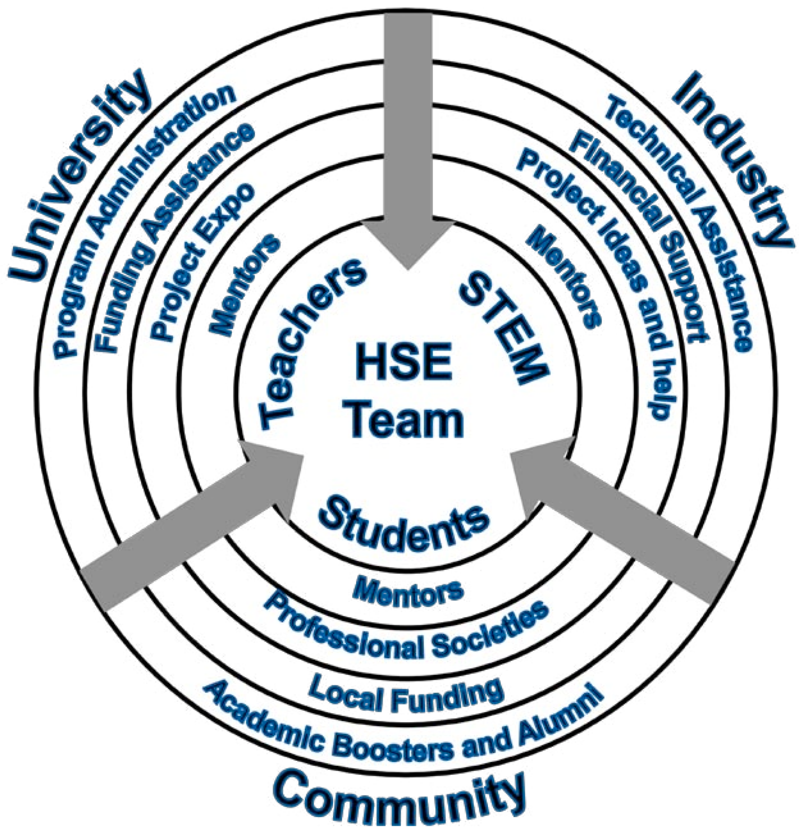

Figure 1. High School Enterprise operating model that illustrates the support system and partners that sustain an HSE team of secondary students.

Teacher-Coach Training – A first exposure to engineering design

The overarching goal of HSE is to entice more students into STEM career pathways in order to help meet the much-documented need. The program aims to attract students from groups currently underrepresented in STEM who may have never considered such a career pathway before their HSE participation.

Many of these students may not have strong math and science computation skills and may have very little exposure to, or knowledge of, the STEM career pathways that are open to them. Even so, these students do have the prior knowledge needed to understand the basic tenets of engineering design. By introducing these real engineering skills, it may be possible to “hook” students by making them comfortable with the design language and with basic design tools, which will build their confidence to look further into engineering as an option beyond their high school years. Because HSE is open to any and all students in grades 9-12, we have the opportunity to reach beyond those who self-select into a typical engineering or STEM course. The makeup of each HSE team is largely up to the teacher-coach and the program strongly encourages that teams be diverse in as many ways as possible. Once these students are participating on an HSE team, it is up to the coaches to devise ways to facilitate learning as opportunities occur. Sometimes these opportunities are structured learning sessions, and sometimes they are impromptu “teachable moments.” To help prepare teacher-coaches to recognize and take advantage of these opportunities, there is a one-week workshop each summer.

In 2008, the design component of the summer workshop was of a general nature and intended as a very basic introduction. The teachers were exposed to the concept of engineering design as a cyclic and sometimes iterative process. They were all familiar with the notion of a “scientific method,” but workshop assessment indicated that, with one exception, these teachers had never before been exposed to the engineering design process. The exception was one teacher who has an engineering degree and had worked as a practicing engineer before entering the teaching profession. Given the historical lack of any K-12 engineering curriculum, it is not surprising that most STEM teachers have little knowledge of engineering fundamentals such as the design process.

During this 2008 workshop, the design process presented was a five-step list as follows:

1. Identify the problem or need
    - Include specifications and constraints
2. Explore alternative solutions
    - Brainstorm, filter, select
3. Decide on the best alternative
4. Create the design
    - Model, prototype, test, optimize, redesign, iterate back to earlier steps if needed
5. Communicate the solution

The teachers were receptive to this version and were able to relate it to their prior knowledge of the scientific method.

Armed with this design introduction and information from the other workshop modules, the teachers went on to coach the HSE teams during the 2008/09 school year. Their year-end presentations and reports showed evidence that students were using the design process and beginning to speak the language of design. Evidence of this is shown in the following sections.

Specific HSE Team Activities and Design Work from 2008-2009

During the 2008/09 academic year, five HSE teams were active, all of them in Michigan: Arthur Hill High School in Saginaw, Davis Aerospace High School in Detroit, Utica High School, Traverse City Central High School, and Hancock High School. A total of 65 students participated and their projects are summarized below:

- Our Mission to be Green: Arthur Hill H.S. students are researching, designing, and constructing a Michigan Natural Green Spot, consisting of a variety of flowering plants, vegetables, and shrubs along with a pathway in an 80 x 130 foot area on the school's campus. It will provide an educational space for the students and a place for the community to visit.

- Underwater Remotely Operated Vehicle (ROV) Engineering: Traverse City Central High School students are designing, building, and testing ROVs and components for a variety of uses. The team has set goals to develop an ROV with deep water (over 100 feet) capability, to develop a cost-effective underwater camera, and to design and build specialty ROVs for exploring under the ice and for capturing video of salmon runs in a local river.

- Underwater Remotely Operated Vehicle (ROV) Competition: Utica Community Schools students participated in the annual MATE Underwater ROV competition. Preparation for this starts early in the school year and extends beyond the end of the year into the summer months. In 2009, the Utica team qualified for, and participated in, the International MATE Finals in Buzzard's Bay Massachusetts in June 2009.

- RC Aircraft Kit: The Detroit Aerospace H.S. "Afterburners" built a 1/5 scale Piper Cub RC aircraft from a kit. They plan to use this to take aerial photos.

- Environmental Consultants: Hancock H. S. PEAK (Partnering the Environment and Academics in the Keweenaw [peninsula of Michigan]) worked as an environmental consulting group focusing on a local watershed area. They performed stream monitoring, mapping, and plant inventory for the watershed.

Each HSE team worked on its project during the 2008/2009 school year. In April 2009, team members from all five HSE teams came to the Michigan Tech campus to participate in the Undergraduate Expo where, alongside about 800 undergraduates (including the university Enterprise teams), the high school teams participated in a poster session and gave formal presentations about their projects. This event gave the secondary students the opportunity to meet HSE peers from other schools, to learn about the other HSE projects, and to visit the university campus. The experience culminated in a banquet for the HSE teams and teacher-coaches. A survey instrument was administered at the banquet to gauge students' perceptions of their HSE experiences throughout the school year. Responses to this survey give several clues about the effectiveness of the program:

- Only 20% indicated they had ever participated in a similar project-based experience before HSE which indicates that this is unlike the learning environments they have experienced.

- When asked to identify the *best aspects* of their project work (open response), 37% indicated teamwork or working with others. So HSE teamwork is a very positive experience for many of these students and may also make the students more receptive to team learning as undergraduates.
- When asked to identify the most difficult or challenging aspect of their project (open response), all but three were able to respond with specific examples. Of these, 28% identified a STEM issue (e.g. wiring, soldering, learning about electronics), 28% identified some aspect of project management or design (e.g., finding enough time, getting information, creating new ideas). Of the three students who did not give an example of a challenge, one responded, "Actually you see we worked good as a team and when we helped each other nothing was hard to accomplish."
- When asked to identify important things learned about planning and implementing their project, many students used "design language" in their open response. Some examples are:
    - " Drawing things out and thinking before we made it."
    - "Get all the information before doing anything major/minor."
    - " … go over your plans before implementing."
    - "… get everyone's ideas and make a detailed plan."
    - "Draw up your plans and calculate before cutting and gluing …"

- For the same question (planning and implementing), it is striking that 50% of the open responses dealt with the management of time (e.g., " everything takes a lot of time")This indicates that these students were actually wrestling with one of the most prevalent design constraints. What a great way to introduce the notion of such a constraint.
- Finally, when asked if they were planning a career in STEM, 70% indicated yes. (Interestingly, nine of the twelve "no" responses came from the sixteen 11th graders.) Of course, this does not confirm that HSE is the cause for these students to go into STEM, but we are very encouraged by such a high positive response.

Design - inherent in the project work

In examining the work done by the HSE teams after the 2008/09 year, we see that the students were faced with several challenges both in project management and design. The way they met these challenges shows a grasp of the some basic concepts in these two areas. Evidence of this is shown in the language used in their posters and presentations as well as in the artifacts produced. Some examples from three of the projects that included a significant amount of engineering design are presented here.

<u>Our Mission to be Green</u>: Constructing a Michigan Natural Green Spot, Arthur Hill High School, Saginaw, MI. This HSE team was made up entirely of 9th grade students: six boys and six girls, nine minority students. The team was coached by a female science teacher with no previous experience in engineering or engineering education. The team met after school once or twice per week as an extracurricular activity (although this work, due to the students' petitioning of the school board, is now considered to be part of their project work required for graduation).

The following comments are excerpts from the team's PowerPoint presentation at the undergraduate Expo in April 2009:

> Roadblocks & Concerns
>
> How to maintain strong meeting attendance?
>
> Established a bi weekly meeting schedule, and decided to maintain a smaller group for year one as we work through basic project issues.

> Being overwhelmed by the project itself since it is such a large endeavor.
>
> Established mini goals for year one, into year two, also sought out advice from trained experts.

These statements show the team's approach to overcoming two specific challenges in project management. The first excerpt identifies a personnel problem in the realm of human resources and provides the approach used to address the problem. The second excerpt is a set of statements that shows the students ability to break a large problem (their project) into smaller parts. These examples indicate that the students would probably be very receptive to tools (such as a Work Breakdown Structure and a Gantt chart) that could help solve the project management problems that they, themselves, have identified.

In Figure 2 a photograph is provided of the scale model of the project area outside the school. The students built this with help from a community mentor with a background in civil engineering. The students chose to build the model to clarify, both to themselves and others, what their project would entail. The model also gives the team a way to try out design solutions as the project progresses (e.g., pathway configurations, feature sizing and placement, etc.)

Figure 2. Scale model of the project area constructed by the HSE team at Arthur Hill High School, Saginaw, MI.

Underwater Remotely Operated Vehicle (ROV) Engineering: Traverse City Central High School, Traverse City, MI. This team was made up of about 15 students (actual numbers varied throughout the year) in grades 9-11: twelve boys and three girls, no minority students. The team was coached by a male physics teacher with no previous experience in engineering, but significant experience in ROV project work. The team met after school once or twice per week as an extracurricular activity.

This team's goals, as reported in the fall of 2008, are listed here:

- Construct an Underwater Remotely Operated Vehicle (ROV) capable of going to 200 ft in depth
- Evaluate an "onboard" power system for propulsion and electrical service
- Create underwater 3-D still images
- Evaluate various "intelligent" control systems
- Implement a system of data collection
- Engineer a neutrally buoyant tether
- Provide a service utilizing ROVs and their capabilities to the surrounding community

It is significant that the students defined a very specific and diverse set of goals. This indicates they have the ability to apply project management tools and would be receptive to tools that would help them meet their goals. All of the goals were not attained in 2008/09, but the team has kept many of them in the plans for this school year (2009/10). With some simple planning tools like a Gantt chart and a Work Breakdown Structure, the team may be able to better judge what is possible within a school year and plan accordingly with more accuracy. There are also indications in the goals that the team was thinking in terms of design functions (propulsion, electrical service, control, creating underwater images, data collection, tethering), design requirements (200 ft depth capability, onboard systems), and design means ("intelligent" control, a neutrally buoyant tether).

The following statement is an excerpt from the team's presentation for the undergraduate expo in April 2009:

> "What is under the ice? To find out, the team designed and built an ROV to go through a hole in the ice to look around."

They named their ROV "Midget." The photos in Figure 3 show Midget without and then with ballast tanks. These photos exemplify the value of giving students time to re-evaluate and improve designs. Short-term classroom projects rarely allow for this level of design iteration.

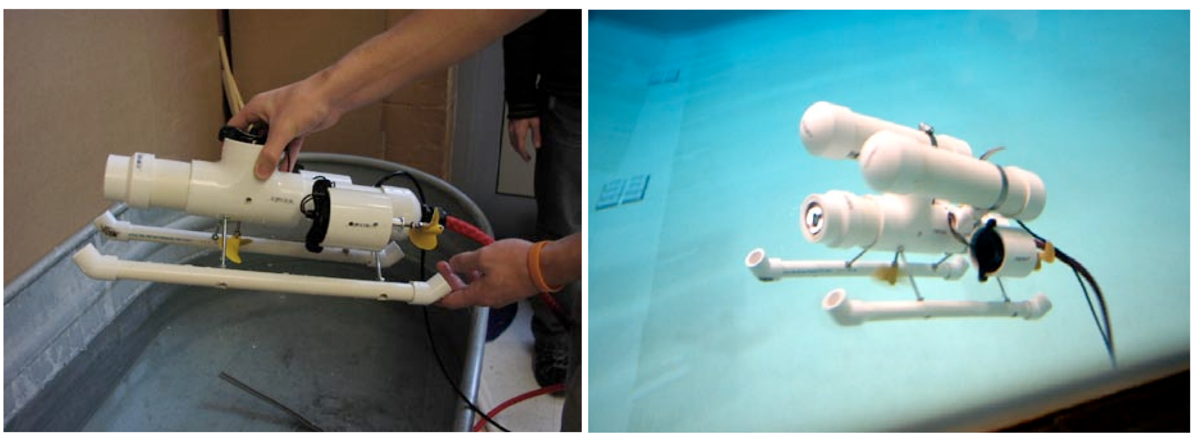

Figure 3. Midget, an underwater ROV, before (left) and after (right) the important design change of adding ballast tanks. Midget was designed and constructed by the HSE team at Traverse City High School, Traverse City, MI.

<u>Underwater Remotely Operated Vehicle (ROV) Competition</u>: The MATE competition, Utica Community Schools, Utica, MI. This team was made up of about 20 students from grades 11 and 12: sixteen boys and four girls, four minority students. The team was coached by a male STEM teacher who has a degree and professional experience in engineering. This team met as a for-credit class every day for two hours. The time spent on the HSE project occurred as part of this class and amounted to 3-4 hours per week.

Students on the Utica HSE team established the following timeline for their project and reported it in their 2009 end-of-year Expo presentation.

- September-Introduce project

- October-Begin research
- November-Brainstorm design ideas
- December-Construct prototype, began ROV construction
- January-Brainstorm appendages
- February-Continue construction
- March-Revise design, make improvements and prepare ROV for competition
- April-Attend Enterprise Expo and MATE Great Lakes Regional
- May-Revise design and make improvements for Internationals
- June-Continue improvements and practice for competition

This team also created a technical report on their project, which was stipulated as a requirement in the MATE competition rules. The following is an excerpt from their report:

> Our original ROV plan included a dynamic ballast system to submerge and surface. Included in our tether was a 0.635 cm (¼") inner diameter plastic air hose as the ventilation hose. A 0.9625 cm (3/8") compressed air line was used to blow out the water from the ballast tanks. In the bottom of our ballast tanks we drilled numerous holes to let the tanks fill with water as the air is pushed through the vent tubes. The ROV floated at the top because the water pressure filling the tank did not have enough force to push air up the small diameter air hose. Some possible solutions we discussed were running another 0.9625 cm tube down the tether but we felt this would add to much weight to the tether. Another possible solution was adding up and down motors to control depth. This was the solution we selected and we added a motor in both the front and the back of the ROV to control possible tilting when picking up the ELSS pods.

The references to revising and improving design in this example, as well as the design revision in the Traverse City HSE project, show that students are indeed using a cyclic design process. This first-hand design experience should prove valuable if/when these students learn about engineering design in the structured setting of a university classroom. Whoever teaches design to these students will not hear the infamous "Am I ever going to use this stuff?" question.

Images of the Utica HSE's ROV are provided in Figure 6. The device is first depicted as a CAD assembly that was produced to help with the design of the ROV, and the second image is a photograph of the nearly complete constructed device. Using CAD technology allowed the team to rely much less on trial and error, which saved a great deal of time. The team's efficiency was noted by the teacher-coach in an end-of-year interview.

Figure 6. CAD depiction (left) and an "Almost Final" photograph (right) of the ROV designed and constructed for the MATE competition by the HSE team from Utica Community Schools, Utica, MI.

Beefing Up the Design Component of HSE

The examples presented above gave clear indications that the HSE program made a great environment in which to introduce high school students to engineering design and project management. The project work gives student participants the relevant experiences that allow them to grasp design concepts with a much deeper understanding than they would gain without such direct application.

Seeing this potential, greater emphases on these topics were made during the 2009 summer workshop. A more extensive unit on engineering design was presented to teacher-coaches who would be working with HSE teams in the 2009/2010 school year. The unit included a much more realistic and detailed presentation of the engineering design process, and the creation and use of a decision matrix using tools such as an objective tree, a pair-wise comparison chart, and criterion metrics.

There were seven HSE schools represented at the 2009 summer workshop. Two participants had coached an HSE team in the 2008/09 academic year, while three had no previous experience but would begin coaching an HSE team in the fall of 2009. There were also two workshop participants who would not be directly coaching the HSE team at their school; instead, they planned to confer with the actual coaches (who were unable to attend the workshop) to transmit the content of the workshop. Also, all of materials from the workshop, such as PowerPoint slides, printed handouts, and supplements, were posted on the HSE website (www.highschoolenterprise.org) so participants and others could access them.

The contents of the summer workshop included many topics surrounding the tasks relating to coaching an HSE team. Most pertinent to this paper, however, is that engineering design and project management were addressed in a three hour interactive session, along with a follow-up discussion which took place the next day. The design session was taught by Dr. Jean Kampe. Dr. Kampe developed and taught first-year engineering curriculum at Virginia Tech for ten years, and much of that content was framed in the context of engineering design. She is now the chair of the Engineering Fundamentals Department at Michigan Tech, home of the university's first-year engineering program. A synopsis of the presentation follows.

Workshop participants were first shown a linear descriptive model of a generalized engineering design process that was based on and referenced to a figure in Dym and Little's design text meant for first-year engineering students.[11] Discussion on this model centered on its linearity and on how the model did not capture the common practice of re-design to improve, something the veteran coaches had seen their students do. A simplified version of this linear descriptive model is provided below in Figure 7, and it is very much like the five-step list presented to the teachers in the 2008 workshop.

The engineering design process:

1. Problem Definition
2. Conceptual Design
3. Preliminary Design
4. Detailed Design
5. Documentation of Fabrication Specifications

Figure 7. A linear descriptive sequence for the engineering design process after Dym and Little.[11]

Workshop participants were then presented with a second model of generalized engineering design in which the cyclic nature of design work was emphasized by the visual used to present the model. This visual is provided in Figure 8.

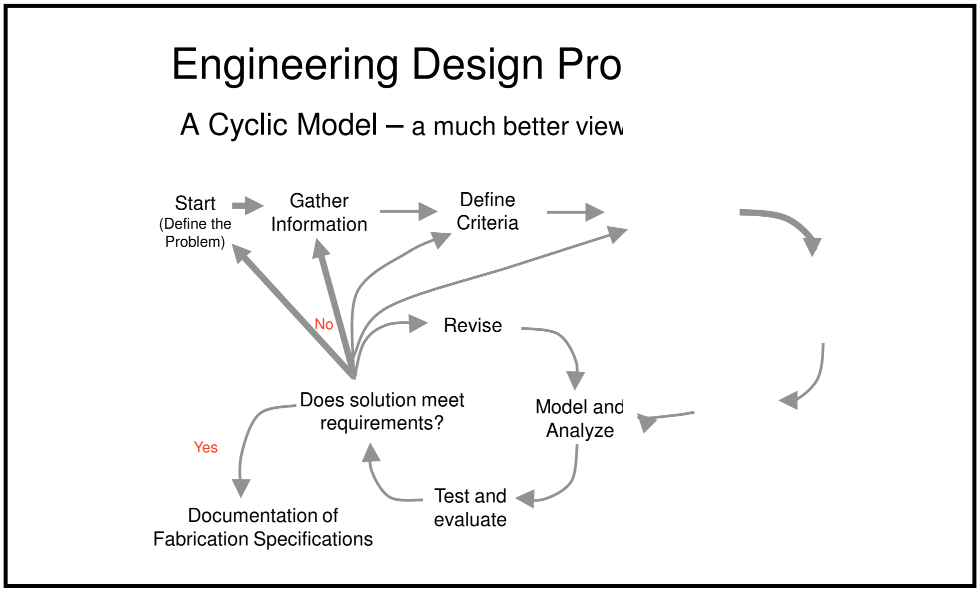

Figure 8. Engineering design presented as a cyclic process by Kampe. [12]

Discussion ensued on which type of model best represents “reality” and there was agreement among the teacher-coaches that a cyclic model was best. It was significant that the two veteran HSE coaches strongly supported a cyclic model as matching with what their teams had experienced. An important advantage of HSE over other learning environments is that the long-term nature of HSE projects (at least one school-year in duration, often longer) allows students time to reflect on “where they are” in a model such as that in Figure 8. With coaches that are fluent in the elementary language and tools of design, and thus able to navigate a more complex model of the design process, there will be many more opportunities to teach real aspects of design than in programs with very tight time schedules.

After this introduction, there was a group activity that compared three very different types of staple removers in a systematic way.[13] The three staple removers and sheets of stapled papers were given to the participants. Then participants were asked to take out staples with each type of remover and guided through a systematic process to evaluate the removers as they went. The activity had participants look at staple remover design both from a user and from a manufacturing viewpoint. This activity was very helpful in presenting the concept of design criteria. It used examples of design criteria in categories such as aesthetics, ergonomics, and performance. Participants were shown how to quantify and communicate the results of the analysis to justify their recommendations.[13] The participating teachers reported that “justification of choice” was an aspect of problem solving that is rarely presented in high school. They also related that this would be a good activity to work through with their HSE teams. Follow-up evaluation will determine how many of them did so, and we will look for evidence of student learning in the project work done in 2009/2010.

Using the results of the staple remover comparison, the workshop presentation next focused on developing a design decision matrix as shown in Figure 9. Participants reported that the concept of a decision matrix was new to them although some had used similar tools to evaluate ideas. Workshop participants reported that the concept was well within the limits of understanding for the high school students they worked with and most thought they would find a place to introduce it as part of HSE in the coming year.

Decision Matrix

Designs / Criteria	Design A		Design B		Design C	
Criterion 1 (weight1)	Rate for A1	Score for A1	Rate for B1	Score for B1	Rate for C1	Score for C1
Criterion 2 (weight2)	Rate for A2	Score for A2	Rate for B2	Score for B2	Rate for C2	Score for C2
Criterion 3 (weight3)	Rate for A3	Score for A3	Rate for B3	Score for B3	Rate for C3	Score for C3
Criterion 4 (weight4)	Rate for A4	Score for A4	Rate for B4	Score for B4	Rate for C4	Score for C4
Score Totals		Sum of A scores		Sum of B scores		Sum of C scores

Score = Rate x weight   Design with highest sum wins!!

Figure 9. A decision matrix presented to HSE teacher-coaches in the summer 2009 workshop.

In construction of the decision matrix, participants were also introduced to objective trees for organizing design criteria and to pair-wise comparison charts, a tool to help with the weighting of design criteria, and even to the concept of metrics used for rating candidate design for each criterion. Introducing these tools was intended to help the teachers understand that engineering design does have methodology at its roots. And, the creation of a decision matrix does not occur just by the wave of a hand but follows a systematic procedure to document design decisions. Discussion on this topic held during on-line meetings with the teachers indicate that many of these tools are not being used, but students are being introduced to the design decision matrix and seem to have a grasp of its use and its limits. Assessment done for this year will attempt to ascertain the degree to which these design concepts and tools were introduced to students and their impact on student learning.

Conclusions

While we cannot yet say that students participating in HSE have a basic grasp of the engineering design process, there is much evidence that HSE student participants have a rudimentary appreciation of design and many opportunities to experience and struggle with the process. It is apparent that the HSE student body is one disposed to enter STEM fields of study (no matter the cause), and the HSE program is provides fertile ground for introduction of design concepts. These things, coupled with the fact that teacher-coaches are being educated to understand the design process, allows for reinforcement of student learning in a way that is authentic and meaningful to these students.

As the HSE project moves forward, we will continue to assess the program with student surveys, site visits, interviews, and formal testing to see if, and to what degree, HSE students understand the engineering design process.

Acknowledgements

The authors gratefully acknowledge funding from the National Science Foundation. This material is based upon work supported by the National Science Foundation under Grant Numbers EEC 0835670 and DRL 0833542. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

References

1. National Academy of Engineering project information, Exploring Content Standards for Engineering Education in K-12, Retrieved in March 2010 from http://www8.nationalacademies.org/cp/projectview.aspx?key=48942

2. Center for Education Reform, Retrieved from http://www.charterschoolsearch.com/, lists 317 charter schools with engineering and/or science listed in its description. This is out of a total of 4578 charter schools in the U.S.

3. Project Lead the Way (2010) Organization Overview, Retrieved from http://pltw.org/sites/default/files/pdf/Organization%20Overview.pdf

4. Infinity Project (2009) Retrieved from http://www.infinity-project.org/index.html

5. FIRST (2010) overview brochure, Retrieved from http://usfirst.org/uploadedFiles/Robotics_Programs/FRC/FRC_Communications_Resource_Center/Flyers/FRC_OverviewFNL.pdf

6. Science Olympiad (2010) brochure. Retrieved from http://soinc.org/2010_brochure

7. ASEE's Engineering, Go For It! (2010) Retrieved from http://egfi-k12.org/

8. National Center for Education Statistics (2008) Digest of Education Statistics Table 5: http://nces.ed.gov/programs/digest/d08/tables/dt08_005.asp?referrer=list

9. Stone, D., Raber, M., Sorby, S., & Plichta, M. (2005). The enterprise program at *Michigan Technological* University. *International Journal of Engineering Education*, Volume 21, No. 2.

10. Sorby, S. & Raber, M. (2005, September). *Learning across boundaries through Michigan Technological University's enterprise program.* 4th Global Colloquium on Engineering Education, Sydney, Australia.

11. Dym and Little (2009) *Engineering Design, a Project-Based Introduction,* 3rd Ed., John Wiley & Sons, Inc. ,Chap. 2.

12. Kampe, J.M. (2009) *Design and Project Management* [PowerPoint slides], Retrieved from Michigan Tech High School Enterprise website: http://www.enterprise.mtu.edu/highschool/coaches/workshopmaterials/Design_ProjectManagement.pdf

13. Malzahn-Kampe J.C., Goff R.M, Connor, J. B. (2005) *First-Year Hands-On Design on a Dime – Almost!.* Proceedings of the 2005 ASEE Annual Conference and Exposition.