AC 2008-2627: STUDENT-INITIATED DESIGN AND IMPLEMENTATION OF SUPPLEMENTAL HANDS-ON FABRICATION TRAINING CURRICULUM IN AN INTRODUCTION TO ENGINEERING DESIGN COURSE: A TQM APPROACH

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Student-Initiated Design and Implementation of Supplemental Hands-on Fabrication Training Curriculum in an Introduction to Engineering Design Course: A TQM Approach

Abstract

Designing and building a prototype has always been an integral part of an interdisciplinary course, the Introduction to Engineering Design (InterEngr 160) class in the College of Engineering at the University of Wisconsin-Madison. In the past, there has been no shop training provided to the students to teach them safe and effective fabrication skills even though the projects require a wide range of fabrication techniques. Around 320 students are enrolled in the fall semester, 2007. These students are distributed into different lab sections. Each of the labs consists of 30 students divided up into two different design teams of 15 students respectively. Each lab is run by an instructor with the help of two undergraduate student assistants (SAs). During the spring and fall semesters of 2007, a hands-on fabrication shop and specialized training program was developed and implemented by the undergraduate teaching staff. They applied the Total Quality Management (TQM) approach from business to engineering education to design the Supplemental Training/Curriculum. The content of the training was planned by undergraduate students who identified skills and knowledge that they felt would have been helpful to them when they had taken the class as freshmen. This supplemental curriculum has been highly praised by students and faculty alike and will be incorporated into the official curriculum of the class in future semesters. This paper will go into more depth about how the program was conceived, designed, planned and implemented by undergraduates in an already existing intro to engineering design course and their outcome with respect to student learning of practical engineering skills.

Introduction/Background

The “Introduction to Engineering Design” (InterEgr 160) course is offered by the College of Engineering at the University of Wisconsin -Madison to their prospective freshmen engineering students. The course was designed to provide the students with first hand experience with working in teams on a design project for real-world clients, which typically consist of community-service organizations. The objective of the course is to introduce the students to the process involved in an engineering design and to provide them with information and experience necessary to make informed decisions about whether engineering is the correct field for them. The course focuses more on the engineering design process than the final product. Thus, the course goals could be summarized as follows:

Upon completion of this course, students should have: [1]

1. An elementary knowledge of the disciplines in engineering, especially the undergraduate programs and extracurricular opportunities available at the our university;
2. A basic understanding of/and experience in the steps and techniques of engineering design;
3. Awareness of some ethical, social, political, and economic influences on and impacts of engineering design;
4. Emerging skills in written and/or oral communication related to engineering design;
5. Introductory skills in teamwork with peers;
6. Preliminary development of habits of mind that engineering study and practice require.

The course structure for InterEgr 160 consists of two fifty-minute lectures and one three-hour lab session a week. The lab sessions are where the fabrication training is a necessity because this is where the students build their design projects. Each lab contains two design teams of 15-20 students and is run by an instructor and two paid undergraduate student assistants (SAs). For the fall 2007 semester, there were around 320 students enrolled for the course which were divided into 10 labs.

Another paid position held by undergraduates in the class is that of the Lead Student Assistants (Lead SAs). Lead SAs are older and more experienced SAs who are hired to help with planning and running the class and also functions as general resources for all of the design groups. The Lead SAs often chosen not to be assigned to a design group and functions more as a specialty consultant. For fall 2007, there were nine instructors involved along with 20 SAs and four Lead SAs. The instructors have freedom for planning their labs but generally follow the design process shown in Figure 1. The key features in the design phases consist of Recognizing the Problem, Defining the Problem, Synthesizing Possible Solutions, Analyzing, Optimizing Solutions, Testing Results, and Presenting these results [2]

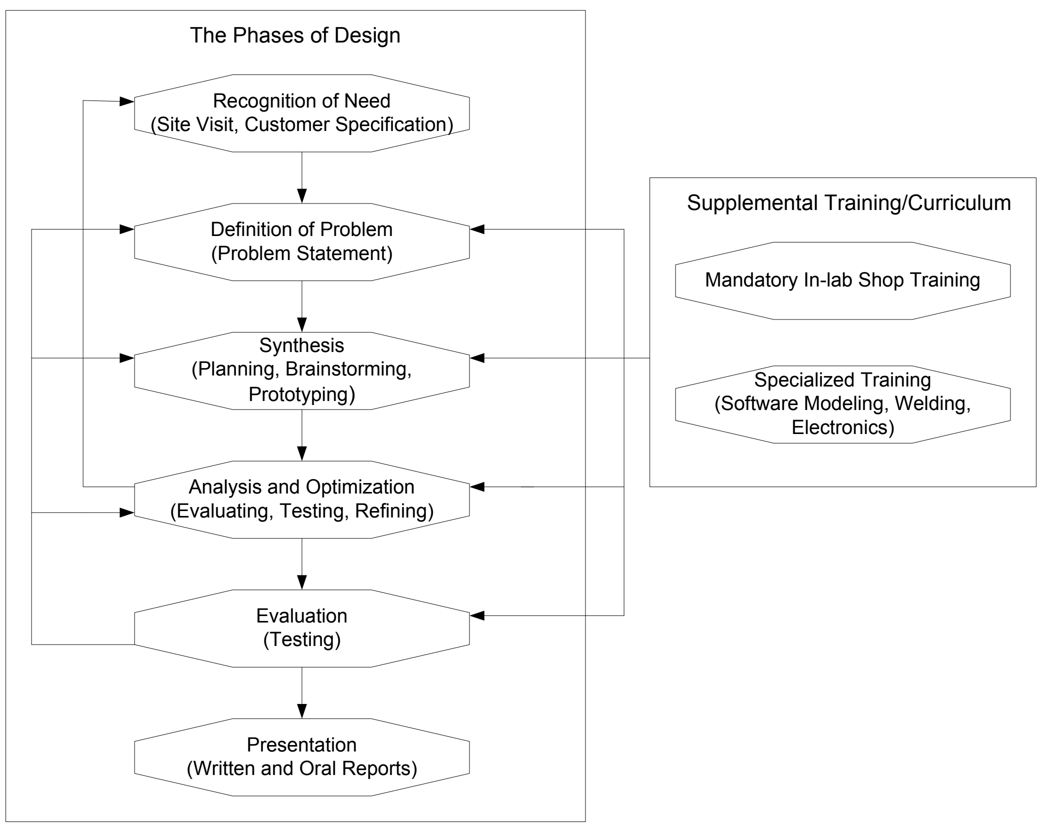

Figure 1. Phases of design [2] and the Mandatory and Specialized Training to support the design phases.

InterEngr 160 is a flagship introductory engineering course at the College of Engineering (COE) at UW- Madison and has proven to improve the retention of engineering students, particularly traditionally underrepresented students. The course also emphasizes peer-to-peer learning and encourages formation of learning communities for shared learning, discovery and team work in a wide variety of technical and non-technical situations. Sanders and her colleagues in [2] discuss in more detail the learning objectives and structure of the course and the success in terms of student retention and performance.

Need for Supplemental Training/Curriculum

The InterEgr 160 course provides the first-year engineering student an excellent opportunity to learn the engineering design process and some basic fabrication and prototyping skills. These skills are used during the Synthesis, Analysis and Optimization and Evaluation steps in the design phase as shown in Figure 1. The fabrication and prototyping skills learned during freshman year forms the foundation that students will use in their design projects for future classes. These skills generate specific interests in students and help them in pursuing certain engineering majors.

Since the students come to engineering as freshmen with wide variety of experience, knowledge of engineering and physical sciences and enthusiasm for field [2]. Past semesters have shown that it is necessary to provide students with fundamental training on some commonly used machines and equipments, general awareness of rules and regulations in the shop and some specialized training based on the projects at hand. In the fall 2007 semester, a Supplemental Training/Curriculum was proposed and implemented by the SAs that consisted of two different kinds of training: a. Mandatory Shop Training for all students, as well as Specialized Training seminars that students could voluntarily enroll in. The Mandatory Shop Training consisted of training on four commonly used machines, and taught the students general safety rules and protocol to be followed in the machine shop. The Specialized Training consisted of seminars and workshops on topics that the students could apply to their design projects. The topics selected for the fall 2007 semester were 3D Computer Modeling, Welding and Electrical/Electronics Instrumentation. This Supplemental Training/Curriculum was implemented throughout the design phases as shown in Figure 1. Throughout the semester we performed assessments of these training sessions in the form of student surveys and participation. Based on the data collected and the student responses we think that the Supplemental Training/Curriculum enhanced student learning and performance. We plan to continuously implement and update it in future semesters.

Supplemental Training/Curriculum: A Total Quality Management (TQM) Approach

The TQM is a management strategy implemented in businesses and industry as a customer-driven, continuous improvement philosophy for improving quality; it is also recently implemented in an educational environment [3-6]. The basic characteristics of TQM includes quality teams, data-based decision making, customer focus and continuous improvement philosophy. Courter has researched at length the effect of TQM curriculum innovation in the InterEgr 160 course on faculty and students' teaching and learning experience and their major outcomes [7]. She has presented a grounded theory of the attributes associated with this TQM curriculum innovation with respects to its positive effects on students' and faculty teaching and learning. We have incorporated this TQM model in our Supplemental Training/Curriculum implementation as shown in Figure 2. We identified the four key characteristics of the TQM model and implemented it in both the Mandatory and Specialized Training sessions. Various tools were employed to help improve student Safety, Participation and Learning Also Kaizen, 5S and Kanban cards were used to help better serve the students in an educational environment. TQM was also implemented in the Specialized Training sessions to decrease the lead time of the training. Lead time is defined in this instance as the amount of time needed to plan the seminars and teach information to the students after the required information was identified. We also implemented a Kaizen-based strategy for continuous improvement of our course [8].

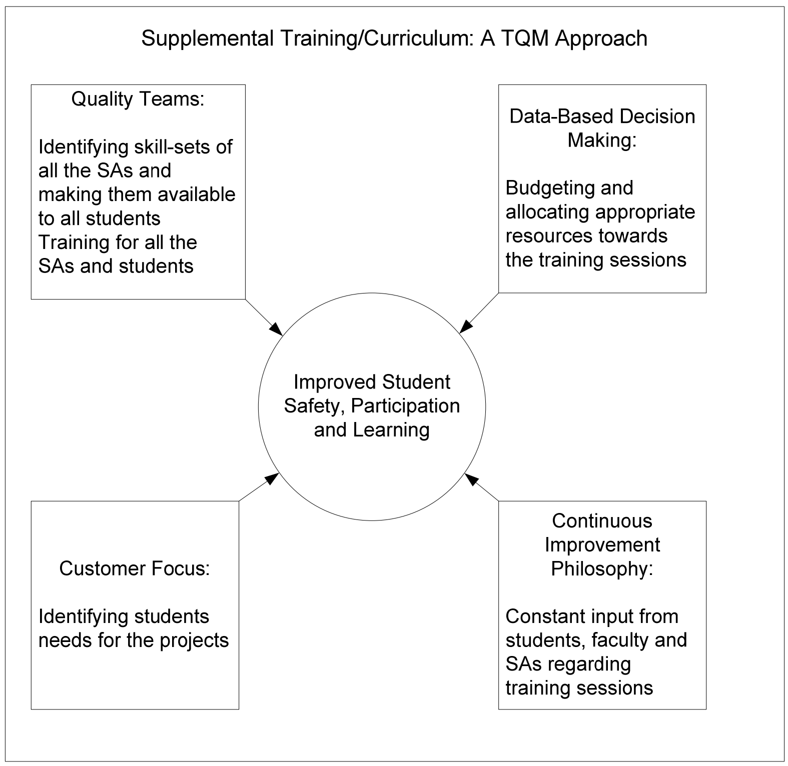

Figure 2. Supplemental Training/Curriculum: A TQM Approach

Mandatory Shop Training

One of the objectives of the InterEgr 160 course is to provide the freshmen engineering students with basic experience and skills in prototype fabrication. This demands frequent access and usage of machines and tools in the machine shop. As a part of our TQM model we emphasized the Customer Focus, which we defined as, meeting the needs of students during the fabrication process in order to successfully complete their design projects. We identified the need for hands-on Mandatory Shop Training based on the number of near injuries in past semesters. Freshmen engineering students enrolling in our class are not required to take any machine shop classes and most of them are unfamiliar with the use of the powerful machines and tools used in the fabrication and prototyping design process. Thus, ignorance is one of the leading causes of accidents and was found to be a major factor in many of the near accidents experienced by the students in the past. When designing the training program we set four main goals:

A. Develop a simple set of general rules to minimize accidents caused by ignorance.

B. Train the students on the four most commonly used machines in the shop.
C. Create training manuals that promoted the safe use of machines above all else.
D. Require the students to physically demonstrate the proper use of machine tools to the SAs.

When choosing the content that would be included in the Mandatory Shop Training we took input from students from previous years, instructors, Student Assistants (SAs) and the shop staff. We used these comments to help us ensure that our training would make the Synthesis, Analysis and Optimization and Evaluation steps in the design phase more safe and injury-free. Based on the feedback, we developed a one hour hands-on Mandatory Shop Training program to be implemented during the students' lab sessions. We offered this training to all the SAs during the beginning of the semester in order to provide them with the necessary skills and expertise that would allow them to help and guide their students. The Lead SAs would administer the training with the help of the SA whose students were being trained. Four machines were chosen for instruction and training manuals were written for each machine. The training manuals helped to standardize the training across all lab sections. This was a necessity because the team of SAs administering the training was constantly changing. Once the student had demonstrated their ability to properly use the machine, they were signed off and were allowed to use that machine when building their prototype.

The Appendix I describes in detail these four main goals and the practical implementation of the mandatory training program. Appendix II provides a manual written for one of the machines selected for training.

Specialized Training

The projects that students work on in our class vary greatly from semester to semester. Because of this a static curriculum of Specialized Training seminars would be ineffective. A system was developed and employed to help the Lead SAs planning the training to gauge what topics should be taught in the seminars. Three different areas were taken into consideration when selecting topics to teach: a. the requirements of past projects, b. the requirements of the present projects and c. the requirements of the students' future classes/education. By focusing on these three areas, the teaching team was able to ensure that the education provided was not only relevant to the students' current projects but also contributed to the students' over success in their education.

To accurately assess the needs of past projects we asked the more experienced SAs and instructors what they thought should be included. Throughout this process we found that many of the same topics came up in discussion and it was also brought to our attention.

The current fabrication needs of the students is dictated by the type of projects being worked on and can vary greatly from semester to semester. Many of the projects used in InterEgr 160 are mechanical or electro-mechanically based and require similar skill sets to be build their prototypes. As a part of the continuous improvement philosophy in our TQM model, the current project requirements were assessed through two main resources: the machine shop staff and the SAs/instructors.

To gain an expert's opinion we asked the machine shop director and shop staff, to read through the project list for the semester to determine some of the possible fabrication questions students might have regarding their projects. Using these questions as a base, a list of possible topics was created with the intent of answering as many of these questions as possible before the students could ask them.

The second source of insight came from a constant, informal questioning of the instructors and SAs that were involved in the day-to-day planning of the projects. The students are given a large degree of independence when forming their designs, which can result in unforeseen skills required to fabricate the projects. The instructors and SAs possess current knowledge of the direction of the projects and possible fabrication skills required when formulating the curriculum. In order to utilize this knowledge we posed the following question *"What fabrication do you think will be required for your students to build their prototype?"* to both instructors and SAs constantly throughout the beginning stages of design. The list of topics created with the help of the machine shop staff was updated and altered as the needs of the students became clearer.

Based on this data and feedback, we went through a decision making process on how to properly budget and allocate resources and time so that we could provide students as much help and training as possible. We narrowed down the list of topics to three different topics: 1) 3D computer modeling using SolidWorks 2006, 2) Metal Inert Gas (MIG) Welding of various thickness of plate steel and square steel tubing and 3) Electronics Instrumentation workshop emphasizing safety when working with electrical instrumentation and hands-on activity on circuit design on a breadboard.

The Appendix III provides in more detail the implementation of these specialized training sessions and the topics covered.

Practical tips for implementation of Supplemental Training/Curriculum

During planning and implementing our training sessions, we integrated the three core ideas from the Delta Program which are Teaching-as-Research, Learning-through-Diversity and Learning Community [9]. Through the Teaching-as-Research approach, we were able to involve systematic and reflective use of research methods into the design of our Supplemental Training/Curriculum. We studied the TQM model which has been successfully implemented into the industrial management practices. We tried to draw a parallel between the business/management environment and educational environment and accordingly designed the training sessions for effective student learning and participation in the InterEgr 160 course. By making shop training mandatory we reached out to a diverse group of students who had little to no shop experience, who otherwise might have been left behind due to lack of proper training. Through the training we gave them confidence to handle the machines and tools for basic fabrications process and provided them an opportunity for participation in the fabrication process of their design project. Learning Communities bring people together for shared learning, discovery, and the generation of knowledge. Within a learning community, all participants take responsibility for achieving the learning goals. Importantly, learning communities are the process by which individuals come together to achieve learning goals. These learning goals can be specific to individual courses and activities, or can be those that guide an entire teaching and learning enterprise [9]. Based on this, we formulated some practical ideas for formation of learning communities during the implementation of our Supplemental Training/Curriculum.

- ***Promote an "undergraduate" image.*** This image can be achieved in many different ways and allows the students to relate to the SAs that are teaching the material as well as the material itself. This image can be created by something as simple as how the Lead SA in charge dresses and talks. Dressing like a typical undergraduate encourages the students to relate as individuals and equals. This increases the effectiveness of the learning community and gets students to feel less hesitant when asking for help or advice.
- ***Limit <u>visible</u> faculty oversight on the program in the eyes of the students.*** It is important that the program has an undergraduate face. Finding an undergraduate student to be in-charge of the program that can function as an individual with minimal faculty support is very important. Instructors should not micro-manage the shop training and seminars but all big decisions should be cleared with instructors before being announced to the students. This necessitates a lot of planning ahead to ensure that the entire teaching team is aware of what needs to be done and when it should be taught.
- ***Let the undergraduate SAs co-ordinate the program.*** This emphasis not only gives the SAs more ownership of the program but also makes the information more accessible to the students, increasing the "learning community-ness" of the class. By promoting learning communities the SAs and the freshmen students will feel as if they have at least some control over their education.
- ***Promote SAs as mentors not just teaching assistants.*** The students should look at their SA as a general source of information. Many freshmen do not have older students to ask general questions and the SAs should fill this gap much like an older sibling would.
- ***Hold SA planning meetings off campus in social locations.*** Holding planning meetings in social environments encourages the SAs to develop friendships outside of schoolwork and the lab. If personal relationships are developed, the SAs are much more likely to work as a group during *"crunch"* time. This group work ethic will improve the projects because the SAs can share their individual expertise with each other and provide better advice to their students.
- ***Compile a list of the SAs skills at the beginning of the semester.*** The list should be made available to the students and other SAs. Having a simple list like this allows the students to use the SAs as resources and promotes the key idea of team teaching.
- ***Create avenues for students to contact the SAs with questions.*** This can consist of something as simple as a bulletin board that students can post suggestions for topics to be taught. It also allows the students to connect with other groups that are encountering the same problems in their design projects. The SAs can then schedule meetings with multiple design groups. This allows the SAs to provide instruction much more efficiently.
- ***Set up an email account for students to enroll in the supplemental training seminars.*** This email account makes the scheduling the seminars much easier by allowing multiple SAs access to the students emails. A simple gmail or hotmail account will suffice.

Analysis and Discussion

We implemented a TQM model-based Supplemental Training/Curriculum as shown in Figure 2 to enhance student safety, participation and learning in the InterEgr 160 course for fall 2007. We conducted an online survey at the end of the semester to get a quantitative and qualitative feedback along with constant input and feedback from the students during the entire fall 2007 semester on the Supplemental Training/Curriculum. The survey collected in fall 2007 was a not required and therefore the response rate was low. It was a pilot program which is a part of a much broader continuous improvement strategy we plan to implement in the upcoming semester for this course. The Figure 3 shows the data for the 123 responses to the ten questions we posted in the online survey. Details for each question follow.

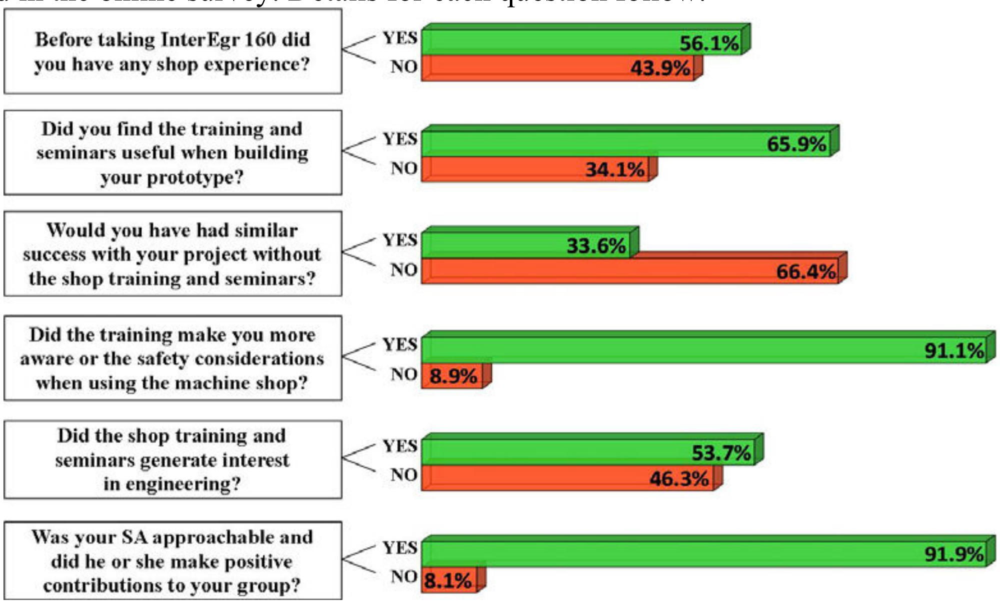

Figure 3: Data for the end of the semester survey given to the students.

1. Before taking INTEREGR 160 did you have any shop experience?

We found that 56.1% of students had some machine shop experience while the rest 43.9% did not have any machine shop experience as shown in Figure 3. Of the 69 students who had some experience working with machines and tool, their skills consisted of the following: woodworking, drill press, hand power tools, sanders and grinders, band saw, table saw, hydraulic press, some sheet metalwork, little bit of arc welding and torch, welding, some CNC and lathe work. Not necessarily everyone had all the skills mentioned above, but some of the above. The students obtained these skills from a variety of different sources such as high school technology education and sculpture class, machining at home basements, dairy farm, personal farm, remodeling of home, shipyard, working with grandfather, maintenance shop, boy scouts and some construction work.

2. Please rate your shop SKILLS before taking INTEREGR 160 on a scale from 1-10. (1 = I've never picked up a tool before,   10 = I've taken a lot of tech classes)

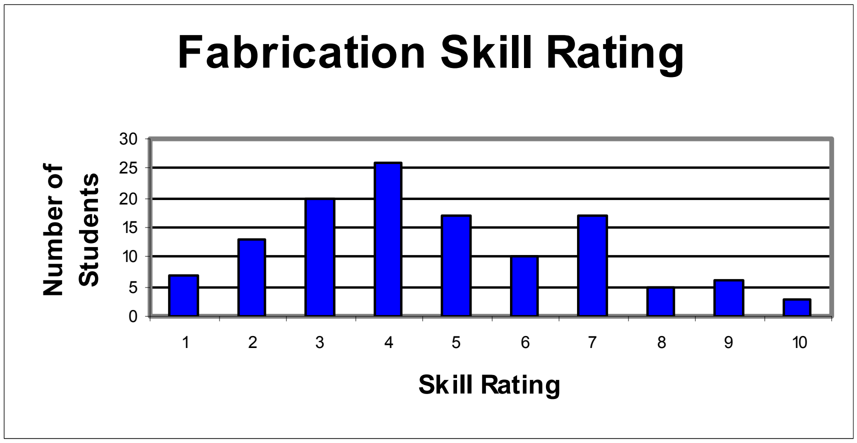

Figure 4. Fabricating skill rating

Figure 4 shows the ratings for the skills of the students on the scale of 1-10 prior attending the InterEgr 160 class. It can be seen that around 68% of students had a skill rating of 5 and below for handling the machines and tools in the machine shop.

3. Did you find the shop training and seminars useful when building your prototype?

As seen in Figure 3 65.9% of students found the mandatory shop training and specialized training/seminars useful for building their prototype while the remaining 35.9% students did not find it useful.

Some of the responses of the students were as follows:
"I could tell from how our project turned out that there is no way we could have done all that without the training. It would have certainly taken a lot longer with out the training."
"The shop training got all of the inexperienced people up to the same level and allowed them to help with fabrication."

4. Do you think you would have had similar success with your project design without the shop training and seminars?

Of the students surveyed, 67% thought that they would NOT have had similar success without the Supplemental Training/Curriculum as shown in Figure 3. Such a high number indicates that the mechanisms developed to provide feedback were useful and helped us provide the students with training that was relevant to their projects. This is one of the most important non-safety measurements when determining if a training program was a success.

5. Did the shop training and seminars make you more aware of the safety considerations when using the machine shop?

Based on the data presented in Figure 3 91% of students thought that the Supplemental Training/Curriculum made them more aware of the safety consideration when using the machine shop. This number is affected by the fabrication level of the students upon enrolling in the course. The more experienced students would not necessarily learn any safety tips during the training. The remaining 9% of students probably represent the more experienced students.

6. What were the two main safety rules stressed during the shop training?

Of all the students who answered this question, the following rules are what most of the students remembered: the 2 inch rule, one should always wear safety glasses, long pants, and shoes, don't leave anything on the machines that you would not want to hit you in the face, know how to operate the machines before you use them and if you don't know what you're doing, ask.

7. Did the shop training and seminars generate interest in engineering?

The data showed that 53.7% of students felt that the Supplemental Training/Curriculum generated interest in engineering as shown in Figure 3.

Some of the student responses were as follows:
"They showed me a really fun part about engineering; we got to make our design a reality, and that was a good feeling".
"I love to work in a shop and by working in a shop it made me more excited about engineering because it is a lot of hands on stuff".
"I love being in the shop and building things so if more of that is involved then I'm more interested in engineering".

8. What is your gender?

This question as asked to get an idea of the demographics of the class. Of the 123 responses 77% of students responded were males and 23% were females as shown in Figure 6.

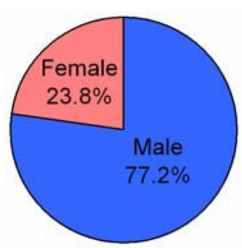

Figure 6. Gender distribution

9. Did you think that your SA was approachable and positively contributed to your project group's learning environment?

Based on the survey results we found that 92% of students felt that the SAs were approachable and positively contributed to the project group's learning environment as shown in Figure 3.

Some of the student responses were as follows:
"She provided suggestions that were broad so we would have to think for ourselves".
"He was a very brilliant and enthusiastic electronics expert, and was very instrumental in developing my electronics skills".
"He was always there to help and operated at our "level" he gave input on what machines could be used for what but didn't completely tell us what to do".

10. Do you have any general comments or suggestion on the shop training and seminars?

Some of the student responses for the following questions were as follows:

"The shop training was excellent and helped me to expand on my knowledge of engineering".
"Overall, they were very well organized and presented".
"Have the seminars more often. I would have gone but could not make the first two so I didn't get a chance".
"There needs to be more welding seminars so that more students have that opportunity".
"Maybe include a few more of the tools, like the miter saw, in the shop training".
"Work on simple things like hand drilling and gluing, too. Some people have no idea how some basic things work".

Conclusion and Future Work

Providing the students and all the SAs with Mandatory Shop Training provided them with basic skills and confidence to use some of the machines and tools in the machine shop and also a foundation on which they can build upon in future semesters. For example, around 68% of the students who responded had a skill rating of 5 and below for handling the machines and tools in the machine shop (rating of 1 corresponded to a case that the student never picked up a tool before).

A little more than 50% of all the students who responded had some machine shop experience but from a variety of disparate sources. We provided the students with standardized hands-on shop training on four different machines, the different tools to be used along with those machines, the safety rules and protocols and work etiquettes to be followed in the machine shop. This Mandatory Shop Training taught the students the correct way to work on some of the machines; it helped them become aware of what is considered as safe and unsafe practice in a machine shop and learning the work etiquettes helped in better communication and relationship with the machine shop staff.

Out of all the responses, 66% of students found the Mandatory Shop Training and Specialized Training/Seminars useful and used some of the skills amongst others they learned such as drill press, 3D computer modeling and design of electrical circuits into actual practice. The students also appreciated the emphasis of safety that was given during these training sessions. Around 34% of the students who responded mentioned that they would have had similar success without the Supplemental Training/Curriculum because their project consisted mostly of assembling the parts than the actual fabrication or they had similar shop training experiences before and also the SAs were able to help them with the prototype design. Thus we think that for most of the students the Supplemental Training/Curriculum was instrumental in the fabrication of their design and provided them enough skills for successful completion of their project. We also found out that the training program made the students aware of some of the safety consideration in the machine shop environment and they were able to recount of the safety protocols that were stressed upon by the SAs during the training.

More than half the students who responded found the Supplemental Training/Curriculum exciting to generate interest in engineering because it provided them an opportunity for hands-on experience and made them more involved in building and fabricating their projects. Almost all the students felt that the SAs were approachable and contributed towards the learning environment of the project group. Providing an undergraduate image to the Supplemental Training/Curriculum and having all the SAs work as a part of a big team, the SAs accessible to all the students, the students found it much easier to communicate with the SAs and ask for help. Thus we were successful in creating a learning community environment. We observed that most of the students found the Supplemental Training/Curriculum useful and well organized, but some of them felt that we should have focused on more basic fabricating techniques such as hand drilling and gluing and include some of tools such as miter saw and that seminars such as welding to be conducted more than a couple times.

As the survey was not made required, we did not have responses from all the 320 students enrolled in the course. As part of our future work we plan to collect multiple feedback surveys from all the students to assess their needs and evaluate the effectiveness of our Supplemental Curriculum. Thus as a part of the continuous improvement philosophy in our TQM model, we plan to incorporate these suggestions as part of our future work in the upcoming semesters.

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Appendix I

A. General Rules

Two main rules were created to help inexperienced students prevent accidents, especially those caused by ignorance. To accomplish this, the rules were made to be very general and overly protective. The rules are a follows:

1. **2 Inch Rule:** Body parts must remain at least 2 inches away from all moving machine parts.
2. **Vise Rule:** When using the drill press the work piece must be securely clamped in a vise and the vise must be securely clamped to the table of the drill press.

These rules might seem odd to an experienced machinist or fabricator because there many situations where the rules must be broken when the correct procedure is followed. The students were made aware of this and told that if they thought that they need to break the rules then they should ask an SA or a member of the machine shop staff for permission. This allowed the more experienced students to prove their knowledge to the SAs and then be given more independence when using the machine shop.

B. Machine Selection

Machines on which the students were trained were selected based solely upon knowledge of what machines students commonly used in past semesters to build their prototypes. Each training session was designed for a specific make and model of machine found in our student machine shop. The reason for this is that even though the basic controls are the same for many machines; they can be located in different places and are not readily apparent to an inexperienced student. Specific directions for each machine helped ensure that all students felt confident using at least four machines in the shop.

The four machines that were selected for instruction were: a drill press, a vertical band saw, sanders and grinders, and a horizontal band saw (cutoff or drop saw). Through experience we have found that these four machines are most used by the students when building their prototypes. More complicated machines, such as lathes and mills, were determined to be out of the scope of the class. Many additional seminars and classes would be required to properly teach the use of these machines and might be added in the future semesters.

C. Training Manuals

We developed detailed training and user manuals to ensure consistent training for all students by the SAs. The manuals focused on the proper use of the machines and stressed on safety. The SAs' past shop experience varied greatly because shop experience was not a requirement during the hiring process. The manuals helped ensure that the inexperienced SAs trained the students correctly by providing them with pre-approved step-by-step directions.

The manuals were approved by the machine shop staff which ensured that the processes were safe and correct. The machine shop staff appreciated our initiative to teach the students how to properly use the shop, thus minimizing the potential accidents. Appendix II provides one such a manual written for the machine Ellis Drill Press. The remaining manuals are posted on the course homepage [1].

D. Hands-On Training

A hands-on training activity was developed that would allow the students to observe an SA demonstrating the proper use of a machine as well as use the machine themselves. A time constraint of 2.5 hours was given for each lab of 32 students. This time period would include a safety lecture, a tour of the lab and shop as well as the hands-on portion of the training. Each training session required three SAs, the SA whose design group was being trained and two additional SAs. The calculated cost per student for the materials involved in the training process is $2.07. The overall cost of training would depend upon the rate the SAs are paid per hour.

Material Selection: High Density Polyethylene (HDPE)

The material selected to be machined was a bar of high density polyethylene (HDPE) with dimensions 0.5” x 2.0” x 24”. HDPE was selected to reduce the amount of force required from the student when using the band saw, sanders and grinders and also to reduce machining time.

Training Process

The 2.5 hours was broken down into the following segments.

Training Outline

1. **Safety lecture** - 10 minutes
2. **Layout work-piece** (draw lines to be cut) -10 minutes
3. **Tour of the lab and machine shop** - 10 minutes

*** Students are broken up into their design sections containing 16 students each. ***

4. **Hands-on shop training** - 60 minutes (Repeated for second design section.)

Safety Lecture: 10 minutes

The safety lecture highlighted the main safety rules for each machine and the general rules for the machine shop. The students need to understand that the rules are set up to prevent injuries and to help them use the shop more efficiently. Most students assume that we are providing them training so that they will not break the machines. Very few realize that this is not nearly as important as promoting safe machine usage.

Layout

After the safety lecture, the students are broken up into groups of four and given 5 minutes to layout their part. Laying out a part requires the students to draw all of the lines to be cut on the work piece with the proper dimensions and colors. They are provided with a drawing, a measuring tape, a square, and colored markers. The drawing gave the students the dimensions and colors of the lines to be drawn. The lines were color coded with the machines that were intended to cut them.

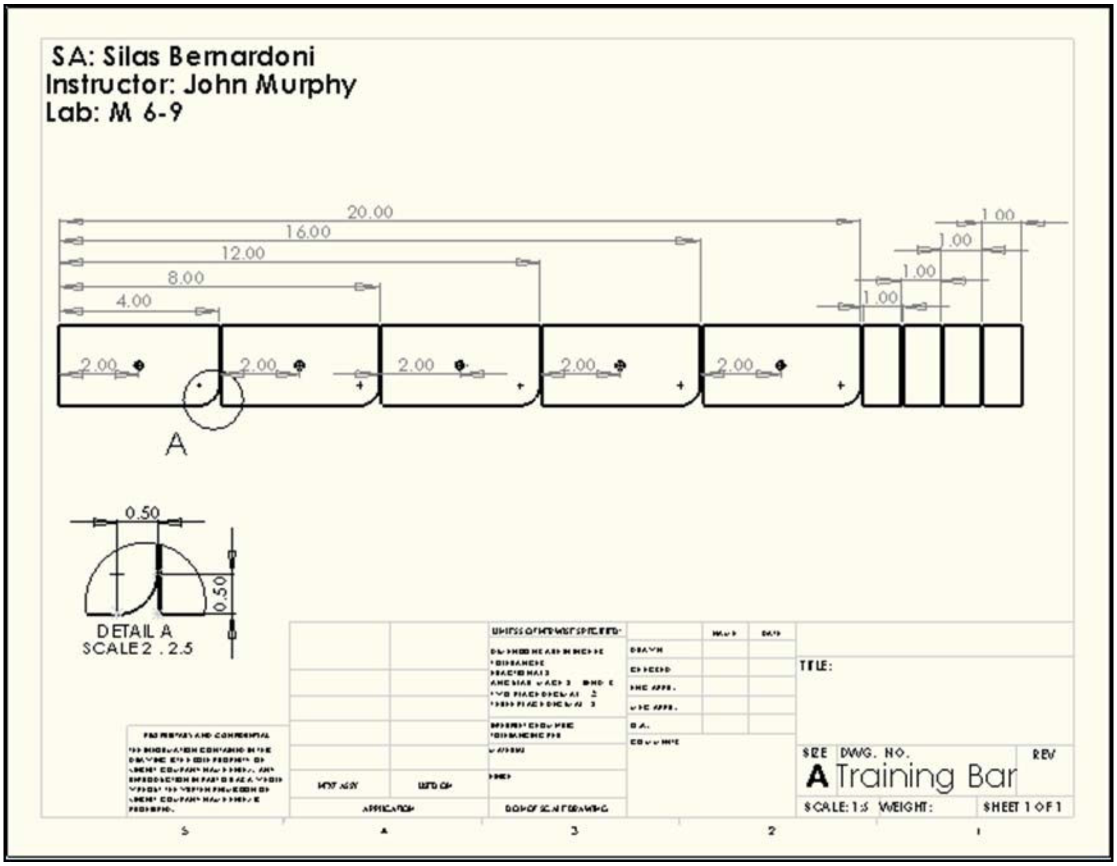


Figure 7. Layout of the part for hand-on shop training

Teaching Team:

The training requires three SAs to facilitate the training process. The hands-on training was given to one design group of 16 students at a time. Each SA helped train their students with the help of one Lead SA along with another SA that was knowledgeable in the shop. The students would rotate between the SAs and machines in their groups of four. The SAs were all required to use the training manuals as outlines when facilitating the training to help ensure that the training was standardized

Demonstration by Students

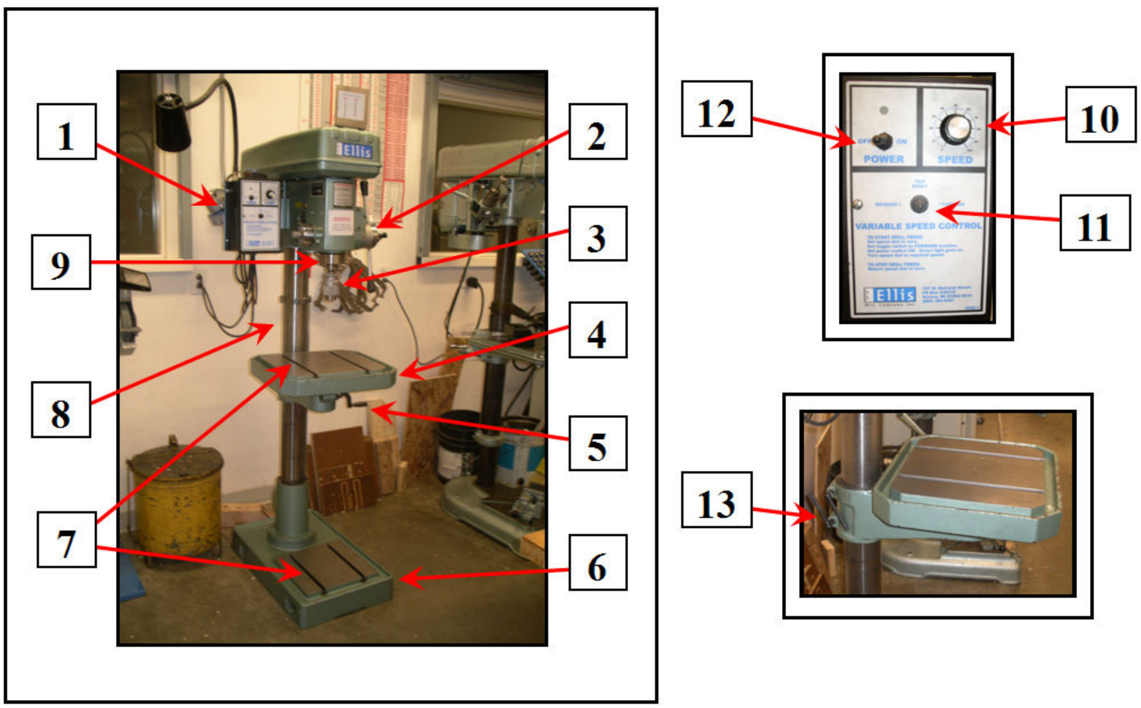
After the SAs finished demonstrating the proper usage of each machine the students were asked to physically demonstrate the proper use of machine using the HDPE bar they had laid-out their . When the training was completed the students were left with a 2”x 0.5”x 4” block with one corner rounded off and a hold drilled in the middle. The dimensions of the block were carefully planned to give the students a physical representation of the 2 Inch Rule. The width of the block showed the students how far 2 inches was; and the length (4 inches) also showed what the smallest piece one could cut with the band saw while following the 2 Inch Rule.

Appendix II

Ellis Drill Press

Model 9400
Ellis Mfg. Company, Inc.

The Ellis drill press is the primary drill press used in the shop for general drilling work. The advantage of using the Ellis over other drill presses is the ease with which the speed can be adjusted. Work pieces of small to moderate size can be successfully drilled using this machine.



Controls:

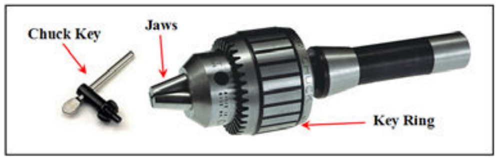
1- Control Box
2- Capstan Wheel
3- Drill Chuck
4- Table
5- Table Adjustment Lever
6- Base
7- T-Slots
8- Column
9- Spindle
10- Speed Dial
11- Trip Reset Switch
12- Arm Handle
13- Table Lock Levers

Primary Safety Rule: All work pieces must be properly secured in a vise, and the vise must also be clamped to the table of the drill press.

Directions:

1. Insert **Drill Bit** into **Drill Chuck**

Jacobs Chuck:



a. Turn the **Key Ring** to the left by hand to open the Jaws.

Note: The three Jaws need to be open wide enough to fit the Drill Bit between them.

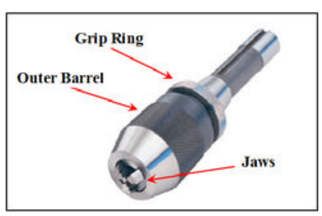
b. Place **Drill Bit** between the Jaws of the Drill Chuck.

Note: Hold the Drill Bit in position between the Jaws of the Chuck until you are finished tightening the Chuck by hand.

c. Turn the **Key Ring** to the right by hand to close the Jaws on the Drill Bit.
d. Spin the **Drill Chuck** by hand to make sure the drill bit is centered in the Drill Chuck.
e. Tighten the **Chuck**.
    i. Insert the tip of the **Chuck Key** into one of the holes.
    ii. Turn the **Chuck Key** to the right until snug.

Note: When tighten the Chuck with the Chuck Key you should always use all three holes to ensure that your drill bit is evenly and securely clamped in the Chuck.

Keyless Chuck:



a. Turn the **Outer Barrel** to the left by hand to open the Jaws.

Note: The three Jaws need to be open wide enough to fit the Drill Bit between them.

b. Place **Drill Bit** between the Jaws of the Drill Chuck.

Note: Hold the Drill Bit in position between the Jaws of the Chuck until you have tightened the Chuck enough to prevent the Drill Bit from falling out of the Chuck.

c. Grab the **Grip Ring** and hold firmly.
d. Turn the **Outer Barrel** to the right by hand to close the Jaws on the Drill Bit.

Note: You should always check to make sure that the Drill Bit is centered in the Chuck.

2. Adjust **Table** height
   a. Loosen the **Table Lock Levers.**
   b. Crank **Table Adjustment Lever** until table is at the desired height.
   c. Rotate the **Table** into the correct position for drilling.
   d. Tighten the **Table Lock Levers.**

3. Secure material in **Vise**
   a. Move **Tensioning Lever** to vertical position
   b. Slide **Sliding Vise Face** open
   c. Insert material into vise.
   d. Slide **Sliding Vise Face** forward until material touches both faces of the vise.
   e. Move **Tensioning Lever** to vertical position.

WARNING: The material is NOT secure. DO NOT DRILL MATERIAL! Additional steps must be taken before the material is ready to be drilled.

4. Position **Vise** for drilling
   a. Turn **Vise** so that the handle or **Twist Bar** is facing left.

Note: If the Dill Bit catches or bites into the material it can spin the entire Vise. Positioning the Vise with the handle facing left ensures that if the Vise starts to spin it will hit the column of the drill press before it hits you.

   b. Slide the **Vise** so that the drill site on the material is positioned directly beneath the Drill Bit.

5. Secure **Vise** to the **Table**
   a. Clamp the Vise to the table using at least two (2) **Clamps**

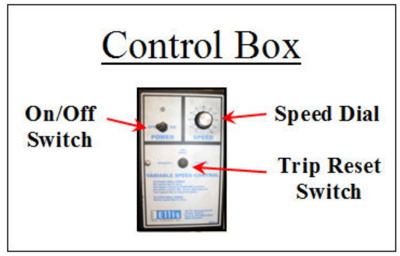
Note: Check Clamp positioning under the Table. The underside of the Table has a lot of ridges and holes. The Clamp faces should not be placed on a ridge of on the edge of a hole. The clamps can slip off and the Vise can come loose.

6. Find Drill Bit speed
   a. Walk to the Machine Information Station.
   b. Click on the Excel document titled **RPM Calculator (drill press)**.

7. Remove all loose scrap, objects, and body parts from the table.

> **!** WARNING: The Drill Press is now on and ready to drill. The Drill Bit will start spinning if you turn the Speed Dial. Do NOT turn the Speed Dial until you are ready to drill your hole

8. Turn Drill Press On
    a. Set **Speed Dial** (on Control Box) to zero(0).
    b. Set the **Trip Reset Switch** to the FORWARD position.
    c. Set **On/Off Switch** to the ON position. The green light lights up.



> **!** WARNING: The Drill Press is now on and ready to drill. The Drill Bit will start spinning if you turn the Speed Dial. Do NOT turn the Speed Dial until you are ready to drill your hole.

    d. Set **Speed Dial** to the required speed.

> Note: If the Drill Bit does not start to rotate when you turn the Speed Dial, with the On/Off Switch in the ON position. Complete the following steps:
> 1) Flip the **Variable Speed Control Switch** to the TRIP RESET position.
> 2) Flip the **Variable Speed Control Switch** to the FORWARD position.

9. Drill hole
    a. Turn **Speed Dial** to the required speed.

> Note: Apply cutting oil to the drilling site if cutting metal.

    b. Turn the **Capstan Wheel** to slowly lower drill bit to the surface of the material and gently bring the drill bit into contact with the material.

> **!** WARNING: The Drill Bit can break from sudden impact and injuries can be sustained from the flying debris. Contact should ALWAYS be made gently when starting a hole.

    c. Apply constant pressure to the **Capstan Wheel** during the entire drilling sequence.

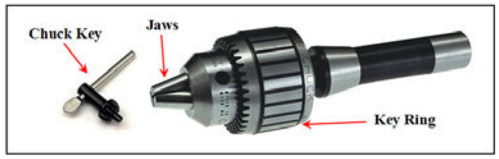
> Note: Cutting Oil should be applied throughout the drilling process when drilling holes in metals and other hard materials.

    d. Return **Capstan Wheel** to the resting position.
    e. Turn **Speed Dial** to 0.

Note: Never turn the Speed Dial to 0 before taking the Drill bit out of the material. The Drill Bit should always be spinning when in contact with the material.

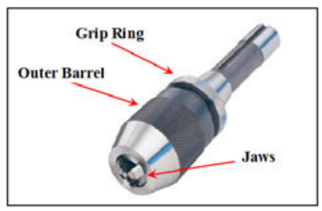
10. Remove **Drill Bit** from **Drill Chuck**

Jacob's Chuck:



a. Wait for the **Drill Chuck** to come to a complete stop.
b. Hold the **Drill Bit** to prevent it from falling while you are loosening the Drill Chuck.
c. Loosen the **Drill Chuck** with the **Chuck Key**.
d. Remove the **Drill Bit** from the Drill Chuck.

Keyless Chuck:



a. Wait for the **Drill Chuck** to come to a complete stop.
b. Hold the **Drill Bit** to prevent it from falling while you are loosening the Drill Chuck.
c. Turn the **Outer Barrel** to the left to loosen the Jaws.
d. Remove the **Drill Bit** from the Drill Chuck.

11. Clean Up
a. Remove material from Vice.
b. Unclamp Vise from the Table.
    i. Clamps should be put back on the hook behind the drill press.
c. Wipe the vice (floor and faces).
d. Close the vise.
e. Remove all scrap from the Table using a vacuum or broom.
f. Wipe all cutting oil from table, vise and drill bits with a shop cloth.
g. Sweep the floor around the base of the Drill Press.

Appendix III

Specialized Training

Specialized Training sessions were held addressing three different topics: 3D computer modeling, welding and electronics. This short list was selected from many other topics because of the topics relevance to the projects as well as the level of interest shown by the students.

<u>3D Computer Modeling</u>
Number of Seminars: 1
Attendance Limit: 45
Duration: 2.5 hours
Hands-On Activity: Modeling simple Lego creations

The 3D computer modeling seminar was taught using the software SolidWorks 2006 and emphasized the uses of 3D modeling applied to InterEgr 160 design projects. The basic skills taught included how to create, alter, and draw parts and assemblies, as well as how to utilize models in the design, fabrication, and presentation of their projects.

These 3D models can be utilized to enhance the students' understanding of their projects and uncover many of the possible problems that would be otherwise remained hidden. Models can give them valuable insight into the constructability of their designs. This added insight gives the students the ability to eliminate many of their flawed ideas on their own without consulting the SAs or instructors. This improves the quality of the projects and often results in the students feeling more ownership over their final project.

Making quality 3D models also helps the students in their presentations by allowing them to look and feel more professional in-front of their clients and peers. This not only gives the students more confidence but also generates more trust and understanding between the client and the students.

<u>Metal Inert Gas (MIG) Welding</u>
Number of Seminars: 2
Attendance Limit: 12 students per seminar
Duration: 2 hours
Hands-On Activity: Welding various thicknesses of both plate steel and square steel tubing.

Many of the projects our students work on are mechanical in nature and often require welding. The welding seminar focused on MIG welding and emphasized the need to show restraint when welding crucial welds in prototypes where people could get hurt. The MIG welding was chosen because of its relative simplicity and versatility when compared to other types of welding. Basic welding skills, knowledge, and safety were emphasized. Two seminars were held in response to a high level of interest shown by students. Attendance was limited to only 12 students per seminar because of the facilities and equipment available. The students were broken up into groups of three and encouraged to work together to improve their understanding.

The seminar was broken down into 20 minute blocks with each block consisting of 5 minute informative talk/demonstration and 15 minutes for the students to experiment with the machines and ask questions. Each block taught the students about a specific aspect or skill when welding, with each block building off of the information presented in the preceding blocks. An example topic for a block was the effects of different "heat" and wire feed settings. The students were not only shown what would happen when the wire feed setting was too high, too low and just right but also how to tell when the settings were wrong. The students were then told to go to their machines and experiment with different wire feed settings.

Electronics Instrumentation
Number of Seminars: 1
Attendance Limit: 12
Duration: 2 hours
Hands-On Activity: Making circuits on bread boards.

The main focus of the electronics seminars was safety and hands-on electrical circuit design. We focused on the safety consideration when operating electrical instrumentation and during electrical wiring using power from the outlet. We discussed the fundamental electrical components such as resistor and capacitors. The basic electrical equations for voltage, current and charge we discussed and how these equations could be used decide the appropriate components needed during the fabrication process. The students were introduced to instruments such as multimeter, power supply and oscilloscope. They were provided a hands-on training session on to use these instruments to build basic electrical circuits on a bread-board.