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Producing the Modern Engineer*

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Modern engineers must perform a wide variety of tasks. Much of the modern engineering curricula prepares students for these tasks by focusing on individual topics such as thermodynamics or stress analysis. Design courses, by their very nature, must integrate a wide variety of areas. These areas include topics that are traditionally part of the engineering curriculum as well as those traditionally considered outside of the curriculum. This paper focuses on the technical contents of a second year design course. However, the course also attempts to integrate other 'non-technical' issues such as communication, teaming and ethics.

INTRODUCTION

THIS PAPER presents concepts from the first semester sophomore level course taught in the Woodruff School of Mechanical Engineering at Georgia Tech. Design courses, in particular, are capable of integrating a significant variety of information and topics within their curricula. This course targets students early in their careers at Georgia Tech to help stimulate and motivate the students for their more advanced classes. It has been shown that exciting the students early in their careers has a positive effect on their subsequent educational experiences [1]. However, the reality that there is only a limited amount of time that both the instructor and student can parse to any particular course limits what can be done in a single semester.

The class used as a base-line for this paper is ME 2110, 'Creative Decisions and Design'. It is a first semester sophomore level course designed to provide the students with a combination of hands-on fabrication experience as well as a foundation for standard design tools. The course is run every semester at Georgia Tech including the summer. Nominally, it has approximately 180 students participating in the class; however, it has been as large as 220 students. Several major topics used in ME 2110 include design tools, fabrication, electronics, communication, teaming and ethics. The class meets as a large lecture for two hours per week. During this lecture, general information is provided to the students for the class. The students also attend a 3-hour design studio where they interact with a faculty member and a TA. These studio sections are limited to 24 students. The design studio, which houses a variety of machine tools, is open approximately 14 hours per day Monday through Friday and 6 hours on Saturday and Sunday. In the studio, the students have an excellent opportunity to bring their paper designs to fruition by actually fabricating them.

DESIGN TOOLS

A variety of design tools are presented in the lecture and then are reinforced by exercises in the studio. Tools such as quality function deployment, functional decomposition, morph charts, decision matrices, design for X, etc., are discussed in the lecture by both faculty members as well as engineers performing the design function in the field. The students, in turn, make use of these tools in their studio sections [2, 3].

While these tools are an important means by which the design space may be expanded and well organized, the students do not often realize their importance or utility. This is due to the fact that many of the systems designed by the sophomores are, by necessity, small scale and uncomplicated in nature. The students often comment that using the tools is only 'busy work'. Therefore, it is important that these tools are discussed and emphasized by personnel from industry. Furthermore a significant number of variations on these tools are used in industry, these variations are also presented and demonstrated to the students.

Issues relating to teaching the students the essence of the tools rather than just the mechanics of using them are critical in motivating the students to really understand how to implement and take advantage of them. If the students do not understand the need and capabilities of these tools they simply implement them in exercises or design projects, but do not truly understand them. This is quite similar to students taking a plug-and-chug approach to their analytic classes. They can plug all of the numbers into the equations and formulas; however, they do not have a feel for the expected results and, therefore, cannot interpret the answers that come from the analysis beyond a cursory level.

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FABRICATION

Probably the most exciting aspect of ME 2110 for the students is the actual fabrication of their designs. There are a number of studio projects in which the students actually build their designs. These vary from simple spaghetti structures to newspaper structures to their major project in which they machine components for an electromechanical device that is used in a competition. One of the major reasons why it is important for the students to fabricate their design is that it demonstrates to the students that designing a system is one thing, designing a systems that has to be built is a much more involved task [4]. Therefore, it was decided that the students should receive some experience in machining parts and assembling systems.

It should also be noted that the machining and fabrication components of this class help to significantly motivate the students in their education. For example, instructors of the manufacturing class indicate that the students perform substantially better in their class given the fact that they have all run lathes and mills. The students have a better appreciation for these machines as well as the processes for which these machines are employed.

Small machine tools, such as the lathe and mill shown in Figs 1 and 2, provide sufficient exposure to the students at a reasonable cost. The simplicity of the manual machines makes them easy to maintain, and their relatively low power reduces their hazard potential. Before using these machines, the students must complete a safety training session. Furthermore, students using the machine tools are constantly supervised to ensure that they are abiding by the safety regulations of the studio.

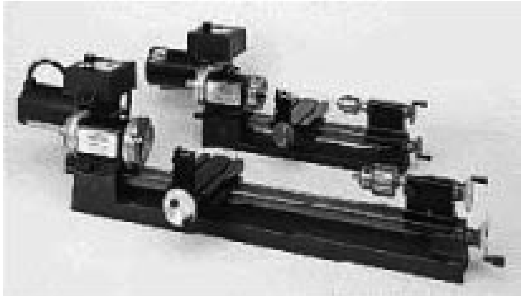

Fig. 1. Standard lathe.

BASIC ELECTRONICS

Most mechanical engineering students are not comfortable with basic digital electronics such as simple microcontrollers. ME 2110 provides a set of hands-on experiences for the students in this area. The results of the electronics studios are better projects in the course as well as increased use of electronics in a variety of other design and laboratory courses. Such multidisciplinary approaches have been show to substantially enhance the student's comprehension of the material being taught [5]. The difficulty with employing computers and digital electronics in an early mechanical design course is the temptation to transform the course into an electronics design course or a programming course. It is, in fact, the students who wish to push the content of the course more towards a programming course as they wish to accomplish more complex tasks generating more complex programming requirements. Thus, care is taken in designing the projects to ensure that they are firmly grounded in mechanical system design.

The students learn to program and make use of a controller that employs a BASIC Stamp 2SX (BS2X) as its main processor (see Fig. 3). It is based on a PIC (peripheral interface controller) chip that is typically found on appliances such as microwave ovens and washing machines. The BS2X is capable of executing approximately 10,000 instructions per second and is designed to be a simple tool for controlling electrical systems. The Electrical Interface System (EIS) was designed in the School of Mechanical Engineering at Georgia Tech as the foundation by which the students can make use of the BS2X. The Mark III EIS, shown in Fig. 4 is the third generation of the unit and is the result of three years of field testing and redesigning the system. It consists of a single printed circuit (PC) board that was designed and populated at Georgia Tech. The BS2SX is directly integrated into the PC board. The design for the board is completely electronic (using a standard CAD system) and is readily replicated via a variety of PC board manufacturing techniques [6].

Two, six Volt gell-cell batteries located beneath the board power the EIS. Students are supplied with a trickle charger to keep the batteries charged. The EIS is programmed in a Windows environment using free software supplied by the producer of the BS2SX. The EIS is connected to the programming computer either via a serial port or via an RF link that is integrated into the system. The RF link enables real-time debugging without the worry of a cable connection. The EIS is used to

Fig. 2. Standard mill.

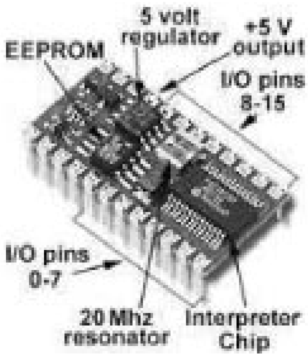

Fig. 3. The basic stamp.

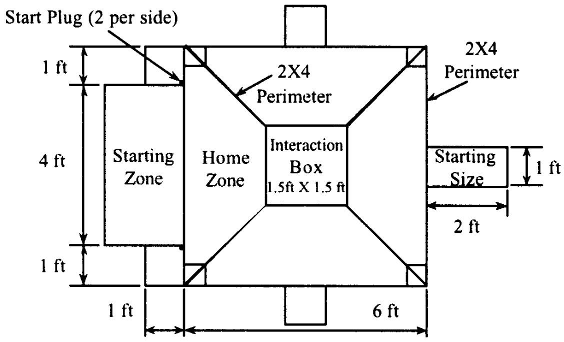

Fig. 5. The competition arena.

interface with a variety of simple sensors including microswitches, range sensors and contact sensors. The EIS also interfaces with a variety of actuators including stepper and DC motors, solenoids and shape memory alloy actuators.

THE COMPETITION/PROJECT

The students use the EIS in a competition that is designed for second year students in mechanical engineering. The competition requires the students to design electromechanical systems that perform a specific task. The course is designed to be fun and to permit a wide spectrum of learning experiences. However, a student team's project grade is dependent on how well their system performs in the competition. Although the competition is the pinnacle of the course, the course grade criteria are designed such that even a student whose systems performs poorly in the competition does not irreversibly harm their grade. During the project the students are given a set of raw materials that they use to fabricate a system. Nominally, they use the small machine tools (mills and lathes, as well as band saws and drill presses) in the design studio for this task. Every term a new project is developed for the students. The project for the spring semester 2001 is described in the remainder of this section.

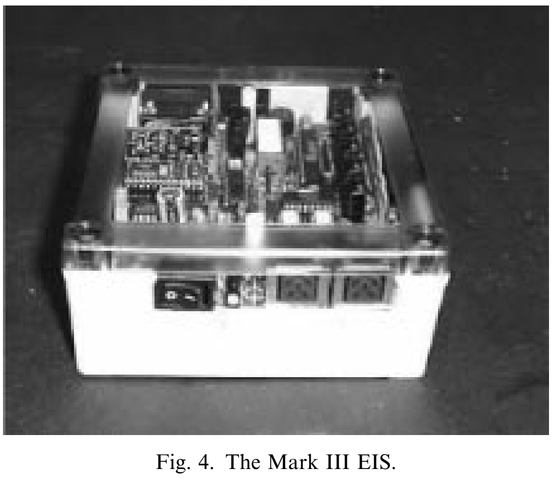

Fig. 4. The Mark III EIS.

The competition is actually a combination of 3 smaller contests that include 'bowling', 'fishing' and 'basketball'. The students' systems have an opportunity to perform each of these three tasks individually as well as performing them simultaneously. All of these tasks are executed in the competition arena or portions of the arena. The arena is a $6\,\text{ft} \times 6\,\text{ft}$ area completely enclosed by 2×4 lumber as shown in Fig. 5. These 2×4's are oriented such that their height is 1.5 inches around the perimeter of the arena. The arena has four home zones separated by 2×4 lumber oriented such that their height is 3.5 inches. At the center of the arena is the Interaction Box, a $1.5\,\text{ft} \times 1.5\,\text{ft}$ area that has three levels for the basketball, fishing and bowling competitions (Fig. 6). Each competition is described in the following text.

Bowling

In this event, the system must knock the table tennis balls from the bowling (ground) level of the Interaction Box (see Fig. 7). There are a total of 10 balls per side on the bowling level of the Interaction Box. For every ball that is in the machine's home zone at the end of the event (-1) points are scored. The starting positions of each ball on the bowling level are considered part of the system's home zone. So if the machine does not move any of the balls, the machine scores (-10) points.

Fishing

In this event, the system must retrieve balls from the fishing (second) level of the Interaction Box. There are a total of 10 balls on the fishing level. The device scores 2 points per ball that is in the

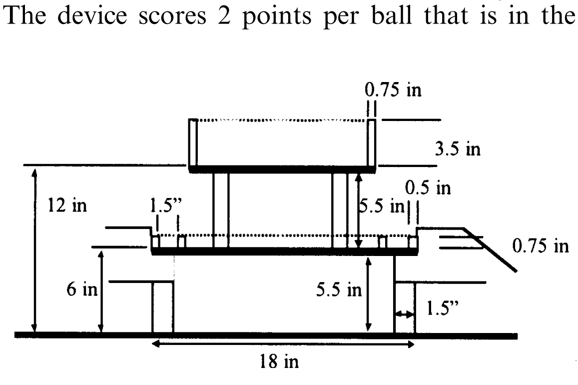

Fig. 6. The interaction box.

Fig. 7. A loaded Interaction Box.

device's home zone at the end of the event. The fishing level itself is not considered part of the device's zone.

Basketball

In this event the team is given 10 balls. Their device must place these 10 balls into the basket (third level) of the Interaction Box. The device scores 3 points for each ball in the basket. Goal tending is legal and encouraged.

The students' objective is to build a machine that scores as many points as possible. Figure 8 shows a typical system that was built by a student team. They are permitted to use energy only from the two 6 V gel cell batteries supplied with the EIS, as well as, energy from five mousetraps and gravity. Their team will be provided with a set of actuators including 2 DC motors, 2 stepper motors, 2 shape memory alloy actuators, 2 solenoids. Only the supplied batteries may power these actuators. The batteries also power the sensors, which are: an IR range detector, several microswitches and the flex sensor. They may also purchase additional sensors as long as the budget remains under $50. To complicate things, three other teams compete at the same time with the same objective.

Fig. 8. A typical student project.

The student's grade on their project is based on a series of oral and written reports detailing the design phases of their machines as well as a score directly related to the machine itself. The machine's scores are comprised of scores from initial events, a qualifying round, a design review and a final competition score. These scores are designed to force the students to begin work on their project making the final result substantially more robust and effective.

The initial events are simply the individual events (i.e., bowling, fishing and basketball) run individually rather than simultaneously. These are held weekly starting four weeks prior to the final competition. Each event is held on a separate week. In the case of this term's competition, four weeks before the final contest, the students' machines had to perform the bowling task. The following week, they performed the basketball task. Finally, two weeks before the final competition, they performed the fishing task. In the fishing and basketball initial events, the students have 5 minutes to run their systems on a track, but facing no opponent. They are permitted to run their machine as many times as they can in the 5 minutes. The number of points their machines score in each event is compared to the amount scored by all other machines in the entire class. Scores for these events are based on how well each individual team's system did with respect to the entire class.

The qualifying round is held the week before the final competition. These competitions are used for the seeding of the final competition. Every machine is guaranteed at least three head-to-head matches during a section's qualifying round. More head-to-head matches may be run depending on the sections' size. The best performing systems from the various studios are pitted against those that performed the worst in other studios. So it is to the students' advantage to have their system perform as best as possible in their studio section. Also, the best performing system in a studio group will receive 5 points; the second best will receive 4 points down to a minimum of zero points.

The design review grade is determined on the competition day (before the final competition). The design review grade is based on the quality of the design as well as the quality of the overall system fabrication as determined by an external panel of judges.

For the final competition, every machine is first run in three individual events (bowling, fishing and basketball). After the individual events have been run, the head-to-head competition commences where each device runs on the main track where it will execute all three events simultaneously. After each round, the score for each team is tallied. The two lowest scoring teams out of the four teams competing on a track are eliminated. Any ties are broken by the sum of the system's score in that day's individual events. The first, second and third place finishers in the head-to-head competition will receive prizes.

ADDRESSING NON-TECHNICAL ISSUES

While this course does address and integrate a variety of technical aspects, there are a plethora of 'non-technical' concepts that the students must master to become successful engineers. The design course sequence in Mechanical Engineering attempts to bring these issues into the engineering curriculum. For example, there are a wide variety of ethical issues that every engineer faces in their career. Early design courses are ideal forums to present some of these issues to the students as they provide an opportunity for the students to think about ethics early in their careers. A variety of case studies and discussion groups are used to make the students think about possible ethical dilemmas in their career. Furthermore, these discussions provide an excellent foundation for the follow-on philosophy class on ethics that the students subsequently take.

Communication, both oral and written, is critical to the success of any engineer and any design. Even the best designs have a difficult time being supported and implemented if the design engineers cannot elucidate their designs in a clear and concise manner. During this course, students are provided with a strict set of guidelines for their written and oral reports. A team of engineering faculty as well as an academic professional whose background is in communications has developed these guidelines. These guidelines are a set of rules that the students use for the remainder of their time at Georgia Tech and, hopefully, beyond their graduation.

One of the most difficult yet critical abilities for students to hone is the ability to work in a team [7]. There is constantly pressure on faculty to have the students work in groups, as this is the norm in industry. However, deriving the necessary individual grades from group performance is a task that is often not as straightforward as a faculty member would prefer. To complicate issues even more, interpersonal dynamics between the students can affect the performance of an entire group in a negative manner. Instructors may need to extend their roles of teacher to referee, as well. During the course of the semester, students are members of several teams. They make use of a variety of teaming tools and learn to work as a team, leveraging their strengths and eliminating their weaknesses.

CONCLUSIONS

The question that must be constantly addressed within the class is, 'How does one balance all of these individual topics while providing an integrated and meaningful experience for the second-year student?' From a more global curricular perspective, issues related to how this wide variety of experiences should be integrated into the students' undergraduate training. The current curriculum of the School of Mechanical Engineering at Georgia Tech tightly integrates the students' experiences through a sequence design courses. Clearly, the focus of the sophomore level course is on mechanical system design and implementation. However, the course must also prepare the students for the situations that they will face when they graduate and are in the workforce. From the technical aspects, a number of lessons were learned in this course including the fact that mechanical engineering students quickly learn and adapt to mechatronics and simple electrical control systems. Students also thoroughly enjoy building systems and machining. In fact it was noticed that the students tend to spend more time on the hands-on fabrication aspects of the class rather than on the use of the design tools. Thus, special exercises were developed to keep the appropriate balance of hands-on fabrication work and design tools work.

Finally, the introduction of a variety of other real-world issues into the course, such as ethics, communication and teaming, provides the students with a more well rounded experience. Feedback from the third and fourth year design faculty indicate that the students perform better in teams and are better equipped to communicate their concepts. Furthermore, when students take their advanced courses addressing ethics (e.g., Ethical Theories, or Ethics and Technical Professions) they have at least begun to think about ethics and how they might affect their careers.

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