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Mechatronics 18 (2008) 179–186
MECHATRONICS

Using mechatronics to teach mechanical design and technical communication

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Received 9 October 2006; accepted 14 January 2008

Abstract

It is commonly accepted that hands-on experiences increase both learning and enjoyment during coursework. Mechatronics projects provide both interesting and relevant hands-on experiences for a wide range of topics including design processes, basic mechatronics concepts, technical communication, and working in a group environment. *ME2110: Creative Decisions and Design* at Georgia Tech integrates mechatronics and technical communication into a sophomore level mechanical design class. This paper describes the course in detail, highlighting the course goals and layout, tools provided to the students, industry involvement, and the main challenges of administering such a course.
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Keywords: Mechatronics education; Mechanical design; Technical communication

1. Introduction

Mechatronics is a discipline that combines elements from mechanical engineering, electrical engineering, and computer science. Given its cross disciplinary nature, it is typically reserved for graduate or upper-level undergraduate courses [1–5]. This trend may be beginning to change as schools introduce mechatronics centered curricula [6–10]. However, it is generally believed that beginning engineering students are usually too inexperienced to handle mechatronics concepts. While this may be true for advanced mechatronics, the basic elements of the topic can easily be grasped by undergraduate students [11–14] and even high school students [15,16].

One subject in which mechatronics naturally serves as a vehicle for course material is mechanical design. Students can be taught traditional mechanical design techniques, such as planning tools, evaluation matrices, and functional decomposition through the use of mechatronic examples and projects. The inclusion of mechatronic projects benefits students, who are able to practice the design concepts that they have been taught, while forming a strong foundation in mechatronics principles. The projects are also rewarding, as they often afford the students their first opportunity to design and build a computer-controlled machine. However, the integration of mechatronics projects into the course poses significant challenges for the faculty. For example, the basic mechatronic concepts, such as electric motor operation and control system programming, must be taught in addition to the mechanical design material.

Such a course also provides an opportunity to integrate oral and written technical communication with a two-fold benefit for the students. First, the students practice the basic tasks of describing and presenting designs. Second, in presenting the design tools used to develop their designs, the students display their understanding of the course material, allowing instructors to revisit those topics that the students have not mastered. Large mechatronics projects provide experience with documenting a complete design process, including discussion of the traditional design and concept evaluation tools. Mechatronics projects

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doi:10.1016/j.mechatronics.2008.01.003

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provide an excellent vehicle for benefits listed above for two main reasons. One reason is that much of the project cannot be seen, such as computer code, making clear and concise description a necessity. The second reason is that such projects can become complex, necessitating thorough presentations and reports. The project complexity also provides the opportunity to require interim reports and presentations, providing the students with additional technical communication experience.

Providing the tools necessary to include a large-scale mechatronics project into a required undergraduate course that typically has 150–200 students per term is a large expense. To offset this, corporate sponsorship is crucial. Partnerships with industry for such courses are beneficial to the school, students, and the industry sponsors. Students are exposed to key industry companies, while receiving experience that is valued by employers.

This paper describes a course at Georgia Tech that has integrated a large-scale mechatronics project into a mechanical design course, called *Creative Decisions and Design* [12,13]. In the following sections, the course goals are introduced and the tools that are provided for the students are described. The course layout is outlined, including the progression of laboratory activities and the final mechatronics project. Then, the involvement of Atlanta area high schools and industry sponsors in the course is highlighted. Finally, the main challenges of the course and solutions to these problems are described.

2. Course goals

The course goals of *Creative Decisions and Design* are:

(1) Teach mechanical design techniques.
(2) Teach oral and written technical communications skills.
(3) Develop basic machining and fabrication skills.
(4) Introduce mechatronic concepts.
(5) Introduce pneumatic concepts.
(6) Develop engineering project teamwork skills.
(7) Allow students to produce a mechatronic device.

The main objective of the course is to teach basic mechanical design techniques including planning tools, evaluation matrices, functional decomposition, and concept evaluation. These topics are introduced during twice weekly lectures and reinforced during weekly lab sessions.

Effective communication, both oral and written, is critical to the design process. As such, it is a critical aspect of this course. Students are introduced to the norms of written and oral presentation of technical project information. This includes the organization of written and oral reports, presentation of information impersonally and concisely, and the integration and explanation of drawings and tables.

As mechanical engineers, it is important that students have a basic understanding of fabrication. However, many students have little or no experience with basic fabrication processes. The machining portion of the course seeks to provide students with hands-on experience with tools such as drill presses, saws, milling machines, and lathes. In an early laboratory session, the students receive training on the tools and then spend 4–5 h manufacturing parts. This exposure to the fabrication process helps the students develop realistic designs and also provides them with the skills necessary to build their own machines.

The introduction to mechatronics is centered around a BASIC Stamp-based stand-alone controller and a supply kit including various electro-mechanical and pneumatic components. The students learn basic mechatronics concepts, such as controlling motors, reading sensor input, and timing actuation.

Throughout the course, students work on various projects in teams of three or four people. This allows the students to practice the more informal aspects of communication and also provides the students with experience in a collaborative design environment. Students typically work in four to five different groups over the course of the semester. This exposes them to a wide range of personality types, preparing them for the variety of people they will work with during their engineering careers.

Many of the previously listed goals are achieved through the final project of the course: the design and construction of a mechatronic device for entry into an end-of-semester competition. This six-week project involves not only the design and construction of the mechatronic device, a first for many students, but also the documentation and presentation of the process. Furthermore, the students must present their finished machines to a panel of judges, including representatives from the industry sponsors.

3. Tools provided to the students

During the course of the semester, numerous tools are provided for the students. These tools include a supply kit containing various electro-mechanical and pneumatic devices, including a stand-alone controller. The supplies allow the students to construct a reasonably complex and powerful machine. In addition, several machine tools and various hand tools are provided for the students to manufacture their designs.

3.1. Electro-mechanical devices

The electronic and electro-mechanical components of the supply kit issued to the students are shown in Fig. 1. The central element of the kit is a BASIC Stamp powered controller box, designed and built at Georgia Tech. The box is capable of driving two DC motors and one stepper motor at various speeds in two directions, in addition to three solenoids. The box has sensing capabilities via two micro-switches, an infrared distance sensor, an encoder, and a flex sensor, all of which are provided as part of the

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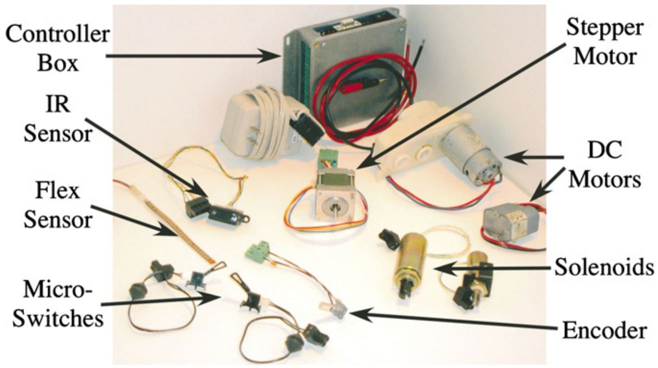

Fig. 1. The electro-mechanical components of the supply kit.

supply kit. To program the controller boxes, the PBASIC programming language is used. Where possible, the kit has been made "plug-and-play" with many of the difficult operations hard-wired into the board and code examples made available. This simplicity allows the students to focus on the integration of the electronic components into a complete mechatronic device.

3.2. Pneumatic devices

The pneumatic supplies issued to the students are shown in Fig. 2 and include a one-way pneumatic actuator, a solenoid valve, and a pressure vessel. The one-way actuator has a stroke of approximately 2 in. and can be extended approximately 15 times using the air supplied from the pressure vessel. The inclusion of pneumatics in the supply kit is intended to fulfill two main objectives. First, because students typically have much less experience with fluid systems than mechanical, the kit helps to provide students with important fluid systems experience. Second, the power dense nature of pneumatic systems greatly improves the variety and quality of student designs.

3.3. Machine shop

The students are given access to many tools for use in the construction of their mechatronic devices. The table-top mills and lathes pictured in Fig. 3 are available and used both in the machining laboratory described in Section 4.3 and the final project fabrication. Graduate teaching

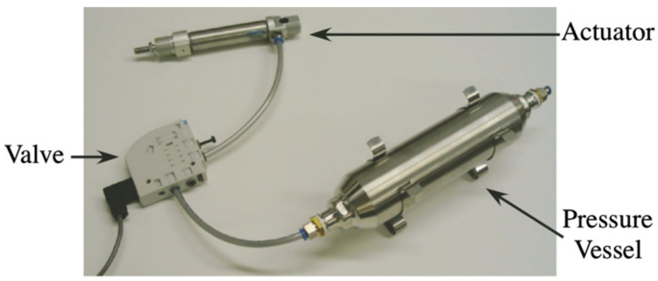

Fig. 2. The pneumatic components of the supply kit.

Fig. 3. Table-top Mill and Lathe.

assistants are present during the machine-shop hours to aid the students in the construction of their devices and to answer questions concerning the operation of any of the tools in the shop.

4. Course layout

The course is divided into two, 1 h lectures and one, 3 h laboratory session per week. During lecture, the students are introduced to a variety of topics that are reinforced during the laboratory sections. The curriculum includes techniques such as quality function deployment, functional decomposition, morphological charts, evaluation matrices, and design for manufacturing.

One challenge of the course is to present the utility of the tools in the context of the course assignments. This difficulty is partially due to the simplicity of the systems to which a typical sophomore level student has been exposed. However, it is important that the tools be presented in a manner that is relevant to the students. This is done by discussing the tools as they relate to the mechatronic projects and/or commercial products with which the students are familiar.

Another challenge in teaching design tools is helping the students to fully appreciate the usefulness of the tool rather than just understanding the mechanics of performing the exercise. This is similar to the battle that teachers of analytical course material fight in trying to reinforce understanding of concepts rather than "plug-and-chug" problem solving. In each case, the lack of full understanding of the concept provides no check for the "plug-and-chug" answers calculated.

The laboratory section of the course is broken into five main parts:

(1) Preliminary projects.
(2) Mini-project design.
(3) Machining.

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(4) Controller/electronics/pneumatics training.
(5) Final mechatronic project.

4.1. Preliminary projects

It is unrealistic to expect sophomore-level students to immediately undertake a complex team-oriented design project. Therefore, the course contains some preliminary projects to expose the students to the design process and encourage teamwork. These projects also serve to introduce the students to the technical writing process and the requirements for oral design presentations. The first project requires the students to build a spaghetti structure. A tower designed to support a golf ball as high as possible is shown in Fig. 4. While the structure varies from one term to the next, from bridges to towers to cantilevers, the basic lab structure remains the same. Each team of students receives two chances, each 45 min in length, to build the structure. This format introduces the students to iterative design.

The second studio assignment is the design and construction of a newspaper structure that must enclose the team's two tallest members. The goal of this studio differs from the first lab in that the students must design the structure and write instructions for another team to build it. During the first week, the team designs their tower and writes building instructions that use less than forty sheets of newspaper and one roll of masking tape. The following week, another team is given the instructions and attempts to build the structure. Various components of both the design and construction are evaluated, including the structure's aesthetics, material usage, and time of construction. The weight supporting ability of the structure is also tested, introducing the students to the destructive evaluation of designs. This lab reinforces the necessity for clear communication of design concepts through both words and figures.

Fig. 4. Spaghetti tower.

A third preliminary project is the dissection of a common engineering product. Typical items include circuit breakers, dead bolt locks, ink-jet printers, and relays. The groups are asked to examine the product and discuss it in a formal, systematic way. They are also asked to recommend improvements to the design based upon their evaluation.

As previously stated, the main objectives of these preliminary labs are to expose the students to the design process, including technical writing and presentations, and to encourage teamwork among the students. Exposing the students to the accepted practices of technical writing and presentation using relatively simple designs allows them to focus on the communication process. Forming a firm understanding of technical communication at this point in the course will allow the students to better document the relatively complex machines that they will develop later.

4.2. Mini-project

One considerable challenge in this course is illustrating the utility and importance of design tools using the relatively simple designs that sophomore level students can create. In order to facilitate a more complex design and reinforce the use of the design tools, a fabrication-less, paper-only design is completed.

Designs have included squirrel catchers, mosquito repulsion devices, car theft deterrents, and laundry chute safety systems. Students gain experience developing system specifications from vague customer requirements and see the utility of the design tools that have been introduced in lecture. In addition, the students are forced into an iterative design and evaluation process. This is an important point, as students are often reluctant to refine and/or abandon initial ideas or to consider alternatives. A third major point of this project is that students can use mechatronic concepts without having to fully develop them. As the course progresses, they gain a better understanding of what would have been required to implement their ideas. The students are required to submit a formal design report and to present their design using accepted technical presentation practices. Typically, this is the first complex design that the students have ever created and presented.

4.3. Machining

Few students have experience with basic fabrication processes. This poses several problems for both students and instructors. The students, having little experience to draw from, lack the intuition necessary to properly generate and evaluate designs. Second, the students have trouble determining the feasibility of constructing their designs. In an attempt to combat these problems by providing the stu-

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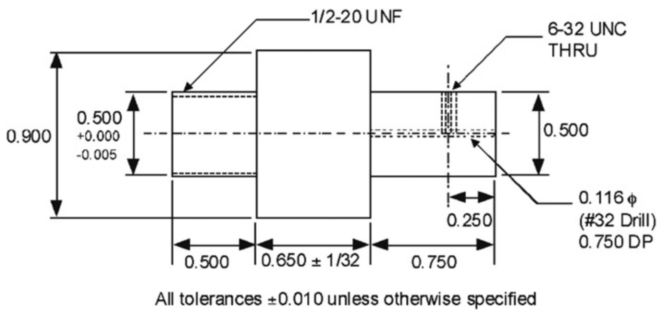

Fig. 5. Mechanical drawing of the coupler.

dents with fabrication experience, the students are required to fabricate a motor bracket and a motor-shaft coupler using the table-top lathes and mills pictured in Fig. 3 and described in Section 3.3. A mechanical drawing of the coupler is shown in Fig. 5. In the process, they are also taught how to use drill presses, lathes, mills, and various saws.

The coupler and bracket are both made from easily machinable Delrin plastic. The table-top mills and plastic stock keep costs low and improve safety. The fabrication of these parts also introduces the students to the fabrication of parts for mechatronic designs.

4.4. Controller/electronics/pneumatics training

During the same time period that the machining is being conducted, the students are also given an electronics lab wherein they are introduced to the basics of using the supply kit, described in Sections 3.1 and 3.2. The students are taught to run the DC and stepper motors in both directions at various speeds, to use the supplied sensors, and to time the actions of actuators based upon sensor input. More specifically, the students are taught the basics of serial communication, pulse width modulation (PWM) of DC motors, analog to digital conversion, and the differences between DC and stepper motors. To complete the lab assignment, the students are required to create programs that utilize a wide cross section of PBASIC functions and demonstrate the basic skills required for the programming of mechatronic devices. This includes conditional statements, various types of loops, incrementing counter variables, using subroutines, reading pin states, and program and loop timing. In addition to teaching the students basic mechatronics principles and how to program their controller box, this lab also serves to demonstrate the capabilities of the supply kit.

5. Mechatronics project

After the preparatory training outlined in the previous sections, the students begin work on the major project for the class. This project lasts six weeks and culminates in a competition between the student-built machines. While the competition theme varies from one semester to the next, the mechatronic devices are usually required to complete three or four main functions, while adhering to numerous design constraints. Several preliminary competitions are held throughout the project. The following sub-sections will outline basic rules and format of the end-of-semester competition, describe the progression of student activities toward completion of the final mechatronics project, and provide a brief description of a past contest.

5.1. Competition theme, goals, and rules

During each term, the theme and goals of end-of-the-semster mechatronic project change. However, the main functions that the student machines must perform remain fairly constant. Typical functions include moving the machine, knocking objects down, collecting items, removing objects from their zone, sensing, and depositing items. Past themes have included *Mission to Mars, The Masters, Shrek, Charlie and the Chocolate Factory, and War of the Worlds*. The systems compete on an arena similar to that in Fig. 6. The arena is a square with seven foot sides and a two foot rotating center section. A 2.5 × 2.5 foot starting zone platform is attached to each side. The student machines begin the competition in this zone. The contest begins via an electronic trigger, which remains active for the 1 min duration of the contest. The students connect their controller box to the track via banana plugs and must program the controller box to sense the beginning and end of the contest.

A number of design constraints are placed upon the student machines. The constraints both provide for a fair competition and introduce the students to design in the face of conflicting requirements. For example, each team may spend no more than fifty dollars to buy construction materials and may only use the actuators provided in the supply kit. The machine must fit inside the volume of a

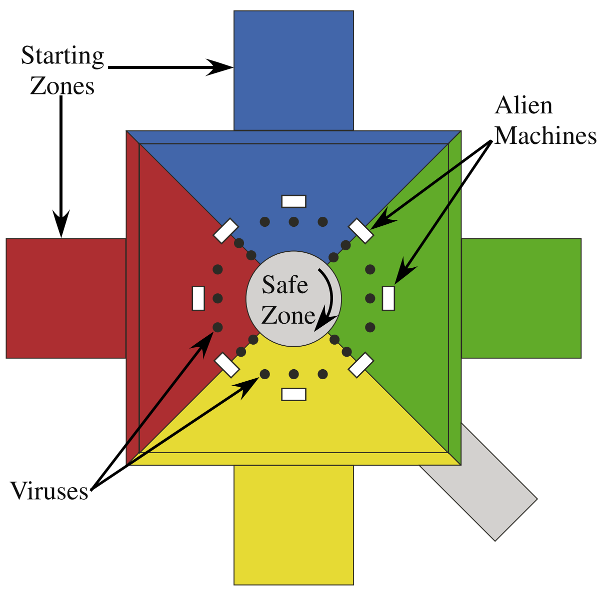

Fig. 6. Competition arena for War of the Worlds contest.

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12 × 24 × 28 in. (length × width × height) box, which they must place over their machine prior to each competition. In addition to these constraints, the students must also consider the aesthetics of their device, as prior to the competition the machines are judged in a science fair on aesthetics, ingenuity, and the quality of the presentation of their devices, further discussed in Section 5.5.

5.2. Preliminary competitions

The preliminary competitions serve two main functions. First, they ensure that students are making progress toward the final competition. Second, the competitions provide the students with absolute feedback on their work. This feedback forces the students into an iterative design and evaluation process, reinforcing the concepts discussed in the lecture portion of the course and covered in earlier lab assignments.

The first such preliminary milestone is a competition between devices built by each student in the class. This individual competition ensures that every student gains experience in the fabrication process and helps provide the skills necessary for each student to contribute to the construction of the final team project. The student machines built during this round are not mechatronic devices, but instead are limited to using two mousetraps and gravity as energy sources. They are usually required to complete the simplest of the tasks required for the final project.

The second preliminary competition is the first team-built, mechatronic device. The machines are driven by the controller box and can use the supply kit actuators, five mousetraps, and/or gravity as energy sources. Generally, machines in this round must complete two of the tasks required for the final competition. From this point on in the project, the students must understand how to integrate the actuators and sensors provided to them with the mechanical elements of their machine, in addition to knowing how to program their controller to achieve the desired results. In the final preliminary competition, the student-built machines must complete all the tasks required in the final competition. This is the first time during which the groups compete simultaneously.

5.3. An example contest – War of the Worlds

The competition arena shown in schematically in Fig. 6 and in the photograph in Fig. 7 is from a past competition based upon the *War of the Worlds*. This competition will be used to further describe the typical functional requirements and design constraints on student machines. The main objectives of the competition were to defeat aliens, infect aliens, collect viruses, and deliver people to the safe zone. Each team was assigned a home zone, defined by the triangle formed by the intersecting diagonals of the square track. The teams were awarded three points for each alien machine knocked over and completely contained in their home zone and one point for each alien knocked over and partially in their zone. For each virus (golf balls), collected into their home zone, the team received one point. If the team was able to place a golf ball into a knocked over alien, the team was awarded an additional five points. Each team was given five people, represented by toy army men. Each person placed into the rotating center safe zone earned the team four points.

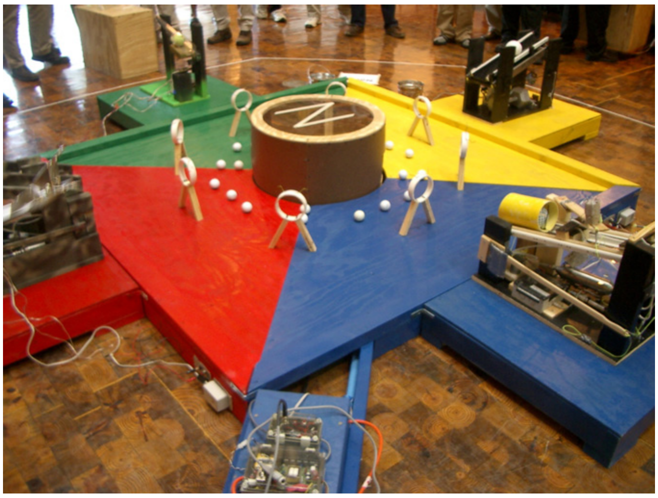

Fig. 7. Picture of competition arena for War of the Worlds contest.

The final competition has become a popular event at Georgia Tech, typically drawing crowds of two to three hundred spectators. Students invite their family and friends to attend and the industry sponsors of the course send representatives to the contest. Former students also usually attend in large numbers. Recently, the event has been webcast to allow those family members, sponsors, and friends unable to attend the competition to view the event.

5.4. Technical communication for the final project

The students are required to write several reports formally documenting the design process. These progress reports are a large part of the course grade and typically include a project planning report and a concept development and evaluation report. There are several benefits to these reports. Narrowly, the students receive significant practice in describing system designs. More generally, these progress reports give the instructors an opportunity to evaluate how well the students understand the design tools that have been presented in lecture and that the students are asked to use as they develop their mechatronic systems. The students are also required to give objective evaluations of their chosen designs and to justify their design choice using the tools presented in lecture. Each report is submitted in written form and presented orally in order to reinforce the importance of effective oral communication skills. The concluding project report combines several preliminary reports into a document that outlines the entire design process and that evaluates each system's perfor-

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mance in terms of the design tools and the assumptions made during the design process. In presenting such an evaluation, the students are asked to clearly define what they learned over the course of the project.

5.5. Industry design review

Immediately prior to the final mechatronics competition, the students present their machines in a design review to a group of judges, the bulk of which are representatives from the industry sponsors of the course. The student groups are judged on the ingenuity and aesthetics of their design and the presentation of the device. Fig. 8 is a picture of a design review in progress. This design review also provides the students with the experience of explaining mechatronics concepts to judges that may not have mechatronics experience. To do this well requires that the concepts are well understood and, as such, provides another check for student understanding of course material.

6. High school involvement

During the spring semesters of 2004 and 2005, high school teams also competed in the design competition; they fared quite well, each time advancing into later rounds of competition. The teams were from high schools that participate in the NSF sponsored Student and Teacher Enhancement Partnership (STEP) program. The STEP program sends students from Georgia Tech to Atlanta area high schools to promote science and mathematics. In each semester, the high school students that participated were part of a robotics club at their high school. The inclusion of the high school students in the contest has proven to be a symbiotic relationship. In addition to the obvious benefits for the high school students, the college students in the course seem to be more motivated upon hearing that a high school team will be competing.

Fig. 8. Industry design review.

In addition to bringing high school teams to the competition, the course has also provided a blueprint for activities at the high school [15]. In Physics classes at the high school, STEP Fellows have used laboratories and competitions patterned after the Georgia Tech course to reinforce Physics concepts. Additionally, the technical writing ideas taught in the university course were extended to the high school classroom, where students were asked to prepare formal reports for labs and competitions.

7. Industry support

Providing the resources necessary for a course such as this one can be an expensive endeavor. Designing and building the controller boxes was a major expense. Likewise, maintenance of equipment, such as the machine tools, and restocking of supplies each semester is also expensive. Significant financial support for the class has come from industry sponsors in the form of donated materials and cash awards.

Sponsors have been eager to support this course for several reasons. The course is taken by all mechanical engineering students at Georgia Tech, making it an opportunity for the students to become familiar with the sponsoring companies. In addition, representatives from the sponsoring companies attend the design review and final competition. This provides a unique opportunity for both students and sponsors to establish relationships that can lead to summer internships, co-ops, and even permanent positions. An additional benefit is that the students see that industry is interested in their work, providing further motivation for the students to perform their best. It also allows the students to understand the proliferation of mechatronics in industry, as reflected by industry interest in the course.

8. Main challenges of the course

One major challenge of the course is the lack of experience of most students in both fabrication processes and the use of electronics and pneumatics. To combat this, a lecture is dedicated to the basic use of the tools in the lab and the electronics/pneumatics kit provided to the students. The material taught in lecture is then repeatedly reinforced during both formal lab sessions and open-lab hours. In addition, a detailed manual for the electronics and pneumatics kit is provided to the students. Students typically become comfortable with both the fabrication process and the electronics/pneumatics kit after this initial "hand-holding" introduction phase.

A stated goal of the course is to develop teamwork skills, and, as such, much of the work during the semester is completed in a group environment. This, however, leads to several challenges. First, the students tend to settle into comfort positions within the groups, especially during the final project. For example, one student might not be comfortable with the fabrication process, so he will volunteer to

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write reports while his teammates build the machine. To combat this, the first preliminary, individual competition was developed, where every student must build a machine. This ensures, along with the machining lab, that every student receives at least some minimal amount of fabrication experience.

A second challenge that the group work poses is in the grading of the course. The amount of group work during the course often forces grade distributions to be fairly tight, making assignment of grades difficult. One way this has been remedied is to include several homework assignments throughout the semester that are completed as individuals. These assignments also serve to reinforce the use of design tools, as the assignments typically involve using one or more tools. The introduction of the individual, preliminary competition also helped to individualize the students' grades. Additionally, students are given the opportunity to review the members of their group several times during the semester. These reviews are used to further individualize the grading process.

9. Conclusion

The course described in this paper uses basic mechatronic concepts and projects as a vehicle for mechanical design and technical communication instruction. The course provides many students with their first machining and fabrication experiences, as well as providing experience in collaborative design environments and with technical communication. The continued evolution of this course has led to a curriculum that is both challenging and rewarding. Significant industrial support has provided excellent resources and indicates the value that industry places on the concepts taught in the course. The final course project and contest provides many students with the highlight of their undergraduate educational experience. Further information can be found on the course website: http://singhose.marc.gatech.edu/courses/me2110/.

Acknowledgements

The quality of this course has been greatly improved by contributions from the industry sponsors. We would like to thank Kimberly-Clark, Fluor, Caterpillar, Milliken, The National Fluid Power Association, Festo, GE Power Systems, Henkel, Shell, Exxon-Mobil, Ford, Toyota, Norfolk Southern, Lockheed Martin, Schlumberger, Proctor & Gamble, United Technologies, Lockheed Corporation, and John Deere for their support. We would also like to thank NSF for its support of the STEP program at Georgia Tech.

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