Enhancing Engineering Problem Solving Skills in a Mechatronics Course

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Abstract

A mechatronics course provides an excellent opportunity for teaching students problem solving skills in a multifaceted engineering context. This nontraditional mechanical engineering course involves the integration of mechanics concepts with electronics and software schemes. The course provides an excellent environment for teaching engineering design skills and exposes students to multidisciplinary problem solving exercises. Students in the course described get a healthy dose of the variety and scope of considerations practicing engineers face when designing contemporary products that involve electromechanical devices. In this paper the authors describe various approaches used in teaching this multidisciplinary course. Build-and-test exercises are used to help students gain a better understanding of technical concepts covered in the course, thus promoting a sense of accomplishment with real world experiences. Students' ability to retain knowledge of concepts taught is improved when the opportunity exists to demonstrate what has been learned. The projects and exercises, as well as the way in which they are executed, are designed to enhance students' decision-making skills and promote good engineering judgment. One course project discussed in this paper involves participation in an industry sponsored robotics contest. Feedback from students consistently indicates that this mechatronics course engages them and helps sharpen their critical thinking skills.

I. Introduction

Engineering educators are challenged with the task of producing globally competitive engineers. Currently, the global market is demanding technically-talented engineers for low wages. Several companies have found a surplus of such engineers in Hungary, China, Russia, and India, where engineers receive average annual earnings of $25,690, $15,120, $14,420, and $13,580, respectively, as compared to U.S. engineers' average annual earnings of $70,000. Initially, the exodus of jobs was blue-collar jobs, and it was believed these were the only jobs in danger of transport. However, after companies began to observe the huge savings they were achieving by transferring the blue-collar jobs, they began transferring many of their white-collar jobs overseas, too. Forrester Research, a marketing research firm, forecasts 3.3 million high-tech and service industry jobs will move overseas by 2015, providing $136 billion in wages. To exacerbate the problem, many foreign nationals are coming to the U.S. to receive their engineering education, working in U.S. companies long enough to learn the trade and make business contacts, and subsequently returning to their home countries with their technical expertise, their business savvy and their lists of business contacts to compete against U.S. engineers for U.S. engineering jobs and contracts. What are engineering educators to do to address the impending impact of outsourcing? Anita K. Jones, a computer science professor at the University of Virginia and member of the National Science Board says, “The challenge for the educational community is to educate people for more sophisticated, knowledge-based jobs…We need to educate for the future, and as always, we need to educate our students better. Competition for jobs overseas doesn’t change our mission.” [1]

More than ever there is a relentless thrust to prepare new engineers to meet the challenges they will face upon entering the workforce. The forces behind this demand include industry, ABET, and those within academia. [2, 3] Areas that are demanding attention in engineering education include decision-making, team work, multidisciplinary activities, manufacturability, and technology utilization. Many engineering faculty members, having been taught themselves in rather focused environments in which each course is taught independently of others, are struggling to incorporate changes into their courses.

Some of the problems that hinder faculty’s ability to meet the demands of industry include the following:

- Traditional departmental divisions
- Time required to plan a new course structure
- Unknown variables that affect evaluation of student performance
- Faculty’s lack of industrial experience

Most engineering faculty desire that their students quickly mature to the point where, given an engineering design problem, they know to do the following:

- Define the problem in engineering terms
- Assemble an appropriate multidisciplinary team
- Independently search for relevant information
- Research prior solutions
- Filter out irrelevant information
- Construct a mathematical/engineering/economic model of the design problem
- Develop conceptual designs to solve the problem
- Conduct proof-of-concept exercises as needed
- Use CAD/CAE/CAM tools to capture design intent and analyze various aspects of the design
- Develop a test regimen
- Iteratively select the best solution based on a structured method
- Research components, parts, suppliers, etc.
- Construct an appropriate prototype and conduct a battery of tests to validate design

The degree to which the typical engineering program actually exposes students to most of the tasks listed above is debatable and varies widely, perhaps even within institutions. Faculty members continue to struggle with just how much of "this stuff" they can include in their teaching.

A mechatronics course provides an excellent opportunity to expose students to some of the design related tasks mentioned above, and thus, help with developing their problem solving skills. Because mechatronics is itself a multidisciplinary course comprising of mechanical systems, electronics, and software routines, it lends itself rather well to bringing students together in a way that actually demands that they reorient their thinking towards a multidisciplinary environment. At Tuskegee University, mechatronics resides under the mechanical engineering department but is also taken by electrical and aerospace science engineering students. Consequently the opportunity exists for each project team to be comprised of at least two disciplines. Thus, the ABET requirement that engineering graduates must be able to demonstrate an ability to function on multidisciplinary teams is satisfied to some degree. The goals for student learning in this three-hour credit course are as follows [4]:

- Apply knowledge of passive and active electronic components
- Understand basic concepts of digital electronics
- Integrate mechanical systems, sensors, and software
- Become more proficient in programming for mechanical system control
- Understand fundamentals of data acquisition

Having taught mechatronics over a five-year period, a need for improving students' problem solving skills was recognized and a strategy to address this need was gradually developed. The balance of this paper discusses components of a strategy used to enhance students' problem solving skills as well as observed improvements resulting from using this strategy.

II. A Strategy for Enhancing Students' Problem Solving Skills

A strategy for improving students' ability to solve technical problems has been devised over the course of five years in teaching our mechatronics course. The primary components of the strategy include the following:

- Hands-on exercises
- Mini projects
- Team formation
- Collaboration across disciplines
- Hardware research
- Failure mode and effects analysis
- Hardware testing

Hands-on Exercises

For most of the students enrolled in this course, the mechatronics course is like no other because of the requirement that they engage in a series of hands-on exercises. These exercises are focused and are assigned as a way of increasing the students' understanding of the theory of operation of a variety of mechanical and electronic devices. The exercises range from simple voltage divider circuit behavior to DC motor control using an H-Bridge transistor arrangement with computer software control. The hands-on exercises are designed to be short and specific and increase in complexity as the semester progresses. Because students learn most when they participate in an active learning task [5], the hands-on exercises are designed to be completed before the next major topic is covered in class. Student teams are given take-home mechatronics lab kits to facilitate timely completion of the exercises and make up for the lack of in-class time to work on exercises. Added benefits of the take-home assignments include the fostering of team interdependence and of learning independent of the instructor (sometimes through exploration). Often, the students are given directions on how to get started. Providing this type of assistance can go a long way in allaying the fears that students might experience when confronted with task of applying theory to practice. Students can also get further assistance and clarification from the GTA outside of class.

Mini projects

In addition to the hands-on exercises, students are assigned a mini project during the semester. This project typically involves synthesis of most of the material in the various hands-on exercises. Students are given about one month for the project. The project is assigned early enough so that students can begin to relate lecture material and hands-on exercises to the project. This strategy breaks the "elephant" into small bites and helps in diffusing some of the mystery involved in applying theory to practice. The robots are constructed using off-the-shelf components to reduce time and effort (and frustration) spent on the project. Thus, unlike a capstone design project, the students concentrate more on design synthesis.

One project is a Ford Motor Company sponsored robotics competition. This competition has become an annual event at Tuskegee University and involves 5 to 6 teams building a robot that autonomously performs tasks ranging from line tracking to obstacle avoidance and payload delivery. While the competition is meant to be a motivational tool for the students in the mechatronics class, in the spirit of competition, participation is extended to the general student body. Thus, teams are formed in the mechatronics class and members of the general student body may join these teams or form their own. The competition provides students with opportunities to engage in design functions such as synthesis, development of product design specifications, build-and-test, construction of parameter diagrams, and failure modes and effects analysis. These activities take place within a clearly defined context with milestones and measurable progress. As part of the judging criteria, students are required to give an oral presentation to a design review panel consisting of industry engineers and engineering faculty.

Team formation

In keeping with the multidisciplinary nature of mechatronics, student teams are formed based on discipline as well as other factors. Because the course is taken mostly by ME students, team assignments are made with at least one EE on each team. Thus students are exposed to a truly multidisciplinary environment in which they have to consider cross disciplinary requirements and seek input from another discipline. Depending on the class enrollment, team assignments also take gender into consideration. When there is a female on a team, it is better to have more than one on each team. Research shows that when women represent a small fraction of a team they can become isolated or marginalized or placed in stereotypical roles that do not permit them to flourish academically. [6]

Most team sizes are limited to three students to encourage accountability. Team members are given an opportunity to grade their team mates' performance on the project at the end of the semester.

Collaboration across disciplines

The multidisciplinary nature of mechatronics and engineering in general is modeled through an informal collaboration between an ME and an EE faculty member. The EE faculty member comes on board as an advisor for the robotics competition and comments on student solutions and suggests improvements. In this course students get to observe the collaboration and discourse between faculty members from different disciplines and are more likely to recognize the importance of having the ability to function in a multidisciplinary environment.

Hardware research

One way to help students better understand the various theories presented in the classroom is to expose them to engineering practice experiences that are similar to those they are likely to encounter in the real world. The hardware selection process provides an opportunity for students to engage in the critical engineering function of gathering information and making informed decisions. In this mechatronics course students visit manufacturers' websites and review technical data pertaining to components that will be used to complete their assignments. Subsequent class meetings would then involve discussions of the suitability of the hardware components to be used in hands-on exercises and/or projects. For most of the students, this is a new, and initially daunting, experience. However, with practice they learn how to filter manufacturers' specifications and ferret out the critical few specifications needed to make their designs function.

Failure mode and effects analysis

The robotics competition requires that students perform a failure mode and effects analysis (FMEA) of their robot as a means of improving the design of the robot. Although virtually none of the students have prior exposure to this type of analysis, they quickly gain an appreciation for its importance in design and manufacturing. It is in FMEA that the multidisciplinary nature of mechatronics is emphasized. Students get to see the various levels of system integration and component and software interaction.

III. Observations

After three semesters of using the approach outlined above, we have observed an improvement in students' problem solving skills over previous semesters. Some of the improvements are difficult to quantify using traditional assessment instruments. However, based on day-to-day interactions with students in the mechatronics class, we have made the following observations, which suggest improved engineering problem solving skills:

- Increased knowledge and familiarity with hardware components, synthesis, and system integration issues
- Increased self confidence in technical ability arising from incremental achievement
- Increased motivation to reach project goals (simply seeing other teams' robots performing the required tasks seemed to motivate others to get the job done)
- Increased exposure to elements of the engineering design process
- More experience managing a mini project of reasonable complexity
- Increased appreciation for timeliness in completing nontrivial assignments
- Better sense of the need for individual responsibility for *knowing* the theory and its application
- Increased familiarity with engineering terminology and language
- Better awareness of need to explore various failure scenarios
- Improved troubleshooting skills
- More initiative in independent thinking and research
- Increased awareness of the need for a multidisciplinary mindset
- Increased awareness of the need for self-assessment of skills and knowledge required to complete assignments
- Improved teaming skills and recognition of individual deficiencies and the need to capitalize on collective skills sets.

IV. Some Suggestions for Success

Much can be done to increase the likelihood that students will acquire better problem solving skills in an engineering course. Mechatronics provides an excellent environment to help students gain important technical and problem solving skills. As outlined above, a few well-thought out strategies can be constructed in such a way to require students to use problem solving methods similar to those used by practicing engineers. However, there are significant challenges that can derail an instructor's plans. Some suggestions for success include:

- When dealing with projects, maintain focus to prevent the course from exploding into a full fledged design course
- Provide enough information for teams to make good first starts, yet still be involved in learning independent of the instructor
- Plan to be flexible regarding shifts in product design specifications and deliverables
- Be reasonably familiar with the operation and nuances of primary components used in hands-on exercises and projects to reduce student frustration
- Be proactive in dealing with team related problems
- Make adequate provisions for hardware failures

V. Summary

For most ME students, the mechatronics course is their first real hardware experience with electronic and electrical devices in a non-laboratory environment. Most laboratory exercises are presented in such a way that students seldom have to engage in the kinds of problem solving skills discussed in this paper. In order to save precious lab time, most instructors prepare the experimental procedure for students who in turn simply execute the step-by-step instructions and report the results along with some analysis and sample calculations. In our mechatronics course students have to do a lot more of the front-end thinking and as a result are encouraged to learn problem solving skills that will be useful in engineering practice. By the end of the semester we consistently identify marked improvement in the way students approach problems, communicate issues to team mates, and seek solutions. Through repeated exposure to the practices outline in this paper, we believe that students' problem solving skills will be greatly enhanced.

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