Introducing a Mechatronic Platform to Freshman Mechanical Engineering Students

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Abstract: *The purpose of this paper is to introduce a Mechatronic platform that was recently developed to enhance Mechanical Engineering curriculum. This new platform provides hands-on experience, encourages innovation, and presents the means for a more holistic education of engineering graduates*.

Introduction

In today's competitive market, there is a critical need for skilled engineering graduates. Historically, students have a good theoretical background after graduation; however, they lack practical, hands-on skills, as well as the ability to think on a system level that is critical for solving real-life engineering problems.

How does an engineering student gain hands on skills and the critical system level understanding of designs they might be asked to create? The era of homemade crystal radios and garage super-charged Ford Camaros is quickly disappearing to be replaced by the immediate gratification of playing video games, instant messaging, and browsing the internet [5]. These original hands-on activities served many purposes for burgeoning engineers. Hands-on experience with real systems yielded engineers who understood that 'real' systems have 'real problems'.

To exasperate the problem more, the field of engineering is facing an even bigger challenge [8]. Historically, the engineering curriculum was formed in response to the workforce needed for the current technology. Today, the technology is changing too fast for the engineering education to keep up with. A new way of teaching engineering must be devised [8]. The engineering graduates of the future must be able to continuously reeducate themselves, adapt to changing conditions, integrate knowledge from various disciplines, and then apply this knowledge in innovative and active ways [4]. In words of Dr Joseph Bordogna, a National Science Foundation Leader:

> "We all acknowledge that scientific and mathematical skills are necessary for professional success. An engineering student nevertheless must also experience the "functional core of engineering" -- the excitement of facing an open-ended challenge and creating something that has never been. Participating in the entire concurrent process of realizing a new product through integration of seemingly disparate skills is an educational imperative."

In her speech [1], Dr. Shirley Ann Jackson also talked about the changes that are facing engineers of the future, and what needs to be modified in the education of the current engineering students. It is evident that the curriculum needs to be transformed into one that is more dynamic, one that will educate the students on how to use new technologies while still understanding how to apply fundamental concepts. Curricula should include a "fun factor" and teach students how to work towards optimal solutions to open ended problems. It is also important that the education integrate different subdivisions of the same field, and that it connects different engineering fields. Finally, it is of outmost importance that the engineers of the future are more than just engineers: they need to be learners and educators, communicators and leaders, professionals that possess a great sense of responsibility and ethics.

In the following section, we introduce *Platforms for Learning*, a way to teach engineering that provides hands-on experience, encourages innovation, and promotes a more integrated education of engineering graduates. Next, the paper describes the Mechatronic platform that is currently used in Mechanical Engineering at Oregon State University in the context of the mechanical engineering freshman orientation course. The paper finishes with the results from the evaluation of the platform in the freshman orientation.

Platforms for Learning

A *Platform for Learning* is a set of common, unifying objects or experiences that tie together the concepts introduced in various classes. The platform gives students a context for learning, a way to clearly observe relationships and dependencies between different materials. It provides a knowledge foundation that is expanded throughout the curriculum. The active nature of the platform forces student to observe how real devices and systems differ from the standard perfect solution commonly discussed in lecture. By being a common factor between different courses, the platform brings better continuity to the curriculum. The platform represents the application of the material taught in class, and how it relates to what was learned in previous classes. It acts to expand and integrate the entire curriculum, as indicated by Figure 1.

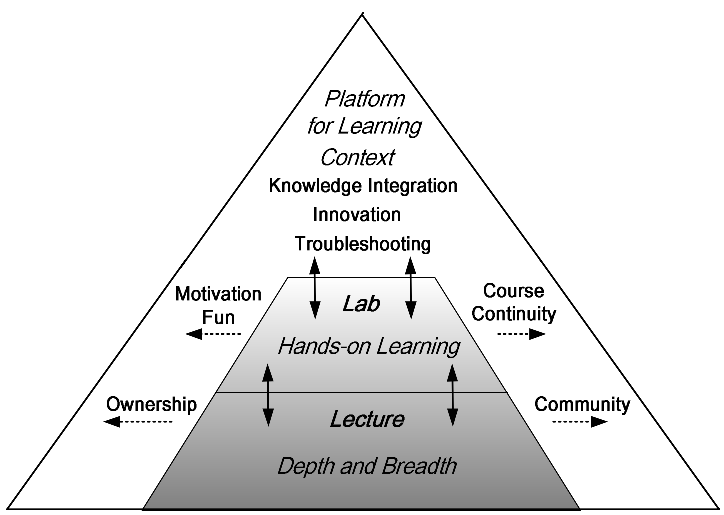

Figure 1 – A platform for learning expands the learning opportunities by providing context, knowledge integration, innovation and troubleshooting experiences. It also created ownership, motivation, community, and course continuity.

Platforms for Learning at Oregon State University

Three years ago, the Department of Electrical and Computer Engineering at Oregon State University started implementing TekBots™, a robotic base the serves as a platform for learning in electrical and computer engineering. The platform went through several stages of revision to achieve better coordination with the lectures and improved 'teach-ability'. It was observed that TekBots had all the characteristics of a *Platform for* Learning shown in Figure 1 and that using the platform improved the students' educational experience [2]. The TekBots platform is now an integral part of the Electrical and Computer Engineering curriculum.

Using what was learned with the TekBots platform for learning the TekBots team developed a new platform for learning targeted at mechanical engineering curriculums.

Introducing the Mechatronic Platform

"In today's environment, innovation and technological breakthroughs more likely are driven by convergence — where disciplines intersect. The sciences and engineering are becoming less separate and distinct from each other. They are blurring, as once singular fields now collaborate, with sometimes surprising, and always interesting, results."

Dr. Shirley Ann Jackson, Ph.D.
President, Rensselaer Polytechnic Institute

During the summer of 2003, a new Mechatronic platform, Figure 2, was created to provide a tool for hands-on teaching of mechanical systems, control theory, strength of materials, and other fundamentals of Mechanical Engineering. The platform was constructed as a kit consisting of a printed circuit board, several motors, and other accessories. Flexibility was built into the platform to allow it to fit many needs of a mechanical engineering program.

Figure 2 – Mechatronix Kit – A new platform for learning.

At the center of the new platform is the Mechatronic board. The Mechatronic board is a control system that uses a microcontroller and onboard motor drivers to control a mechanical system to achieve a goal. The functionality can be broken into three sections: input, output, and processing. The main features of the board are shown in Table 1.

To complement the Mechatronic board, the kit includes a beginning complement of sensors and motors. These components give students enough pieces so that they can learn about mechanical engineering without being completely inundated by too many complex devices. The additional parts included in the basic kit are; two small DC motors, three 'leaf' switches, one 'lever' switch, six rechargeable NiCad batteries, a programming dongle, and an IR sensor.

Digital Inputs	By connecting a simple on/off switch to the input ports of the board, a user can control the motors connected to the output ports. Furthermore, the board is equipped with Analog to Digital Converter (ADC) inputs, so that the motors can be controlled using a value on a scale of 1 to 1024, instead of just using 0 and 1 values (on and off). This feature makes control of the board more flexible.
Integrated Motor Control	There are two high power and two low power motor drivers on the board, making it possible to have up to four small DC motors running at the same time. The motor drivers are capable of providing 0.5A (low power drivers) and 1A (high power drivers) of continuous current in either direction of the motors. Additionally, the motors can perform electronic braking.
Simple-to-Connect Screw Type Terminals	Motors and switches can be easily connected and disconnected from the board by plugging the wires into the terminals, and then tightening down the wires using a screwdriver. This provides a solid, reliable connection without the inconvenience of soldering.
AVR microcontroller	This chip is the heart of the board. It can be programmed to control the motors depending on the digital input. Programming is done easily by connecting the board to a PC using a programming dongle that is included as the part of the kit. The chip uses Pulse Width Modulation (PWM) to control how much power is delivered to the motor drivers, which determine how much power is delivered to the motors. As a result, the students have full control over the speed at which the motors are turning, in addition to the directional control.
Simplified Programming	The board is programmed using a library of simplified functions created as a part of the platform. This is primarily intended to enable the students with no prior programming experience to program the board. The extended benefit is that by using this board students actually learn the basics of programming. For users that are familiar with the C language, there is an opportunity for even greater control and more efficient algorithm design.
Digital Switches	In case the students have a low power electrical device whose operation needs to be controlled, the Mechatronic board is equipped with two additional ports that act as digital switches. These ports are connected to the AVR microcontroller, and can be programmed to be turned on or off, depending on the application.
Expandability	The Mechatronic Board was designed to have the capability of adding serial (RS-232) and infra-red (IR) communication, by simply soldering additional parts to the existing board. These features could be useful in upper-level Mechanical Engineering classes for building more complex systems where several boards need to directly communicate in real-time. Also, a daughter board can be mounted on top of each Mechatronic Board. This way all of the capabilities of the AVR micro controller could be used by another board.

Table 1 – Summary of the Mechatronic Board Features

The Freshman Mechanical Orientation Course

The Mechatronic platform was first introduced in Oregon State University's freshman orientation to mechanical engineering, ME101. The main goals of this course syllabus are:

1. Formulate and solve simple engineering problems, including the use of standard engineering format, estimation and dimensional analysis.
2. Identify and describe the major disciplines within engineering, and areas within mechanical engineering.
3. Identify and describe the operation of basic mechanical systems.
4. Describe basic group creativity and teamwork concepts, and successfully apply those concepts as a productive member of a team.
5. Communicate technical information through written, oral and graphical means.
6. Describe the basic concepts of professionalism and ethics.
7. Develop an understanding of engineering principles through the hands-on, real world design and troubleshooting of a mechanical system.

The class consisted of lecture, lab, and recitation. Lecture and recitation were mostly used for explaining theoretical concepts, while the lab time was reserved for hands-on exercises and a term-long design competition.

The design competition was central to the freshman orientation course. The goal was to design, build, and implement an autonomous system that accomplishes a specified task using the Mechatronic platform. This competition exemplified some of the fundamentals of Mechanical Engineering: working in groups, having an open-ended solution, working with real materials, troubleshooting, and communication of ideas. Most of all, the goal of the competition was to give students their first design experience and a feel for what mechanical engineers do.

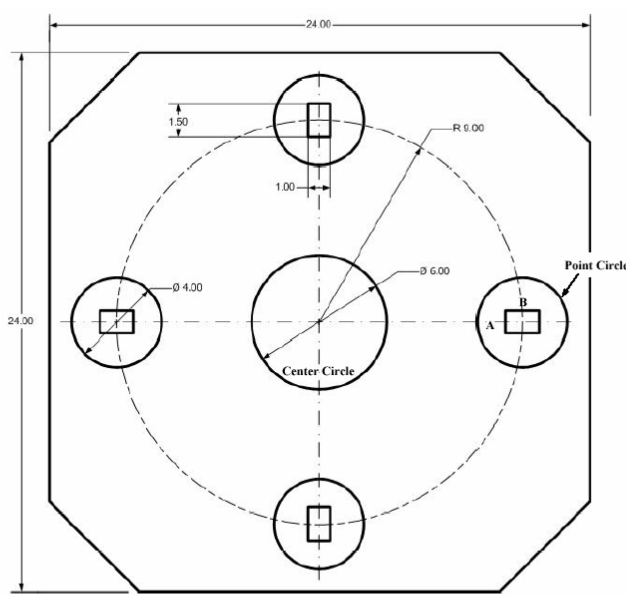

Figure 3 – Competition Area. Dimensions are given in inches.

This year, the task consisted of building a system that would move four rectangular metal blocks from the Center Circle to the four Point Circles of the Competition Area, shown in Figure 3. For the competition, students worked in randomly chosen groups of three. They were encouraged to buy or build any hardware they deemed necessary, and had access to a machine shop for a few hours each week. As a result, designs were limited only by students' imagination and the amount of money they could spend. In this way, the competition closely emulated real engineering projects.

At the beginning of the term, students attended a presentation on design given by a practicing mechanical designer. This presentation helped to excite students and give a few useful pointers on the design process.

For the final competition, designs were judged based on system performance, aesthetics and overall engineering. Students presented a great diversity of ideas, both in conceptual approach to the problem, and different realizations of conceptually similar solutions. No two designs were alike with each team expressing themselves through their design. Figure 4 shows some of the designs students presented.

The Mechatronic Platform in Use

The mechatronic platform supported the core learning objectives of the freshman orientation in many ways, from helping students to communicate technical information to large audiences, to giving students a chance to experience how electronics, programming, and mechanical systems interact.

For example, one of the designs shown in figure 4 named 'Down on the Farm' relied on very simple mechanical principles and electrical controls. This design used gravity to help perform the task of moving blocks. The blocks started at the top of long ramps and when activated a motor drove a cam that pushed all of the blocks onto ramps that guided them to the correct landing sites. This simple mechanism embodied many concepts learned in lecture including friction, gravity, and 'keep it simple' design.

Another design that was presented, figure 4, named 'In the Army' used a more complex control system. This design relied on a series of pulleys and wires connected to each block that ran to motors for guiding the blocks into position. This design was a more complex design, but it did have flexibility. Students understood and talked about how they could easily change where the blocks ended up by simply reprogramming the system rather than redesigning the structure.

Many other designs were presented showing a vast array of different techniques with students making real design and engineering choices while building their systems. Table 2 shows a summary of how the mechatronic platform successfully supported the freshman orientation course students to create these designs.

Connecting Lab and Lecture	In addition to providing hands-on experience, the Mechatronic platform was used to complement the lecture by making abstract concepts more tangible for students. For example, following the lecture on torque, students performed a lab exercise using the Mechatronic platform, where they were asked to generate the torque vs. speed graph for a motor from their kit – a direct application of the lecture material.
Communicating Technical Knowledge	Students were required to use the platform in their designs. While designed to be easy to use the platform requires some technical knowledge to understand. Students in their groups shared information and gained experience in small group communication.
Multi-disciplinary Knowledge	The platform bridged three important areas of understanding; mechanical, electrical, and programming. Each group had to collectively understand all of these aspects and how they affected each other.
Easy Experimentation	The platform had multiple examples that students could try, from experiments with torque to programming techniques for controlling mechanical systems accurately.
Design Skills	The versatility of the platform allowed students to truly design what they wanted to design. The system allowed for both very simple control, and very complex control.

Table 2: The mechatronic platform supports the freshman orientation course.

All Roses Have Their Thorns

Students using the mechatronic platform found it to be a rewarding experience and were excited to invent and create using the knowledge they had about mechanical systems, electrical systems, and programming. However students also learned about what commonly happens when a design is implemented. The platform helped students build troubleshooting ability by allowing them to create many unforeseen problems.

Mechanical Challenges

One of the major mechanical design challenges that was observed in student designs was leverage. Students often did not take into account that the materials they were using to construct their design had weight so when long armatures and levers were built they would be too heavy to work correctly. Students had to troubleshoot and revise their designs to correct these types of problems. Some solutions included adding more support struts, using lighter materials, and complete redesign.

Electrical Challenges

Electrically, students also had to come to grips with real systems. Several groups built electromagnetic devices to move the metal blocks. One team as an example tried to design an electromagnet that would draw 30 amps of current at 12V. When they hooked this design up to their power supply, the resulting light show demonstrated that they had some issues to resolve. Some of the solutions seen for electrical problems like these were systems redesign, and purchase of a pre-made electromagnet.

Figure 4: Some of the designs presented during the ME101 design competition

Programming Challenges

In programming students were also not immune to issues. An example is how many students would try to drive motors very quickly to move heavy loads, and then stop them and immediately try to take a voltage measurement using the onboard ADC. When the motors would stop however, the large magnetic field created by moving a heavy load would collapse and change the ADC measurement. Students had to develop programs that would accomplish this. Solutions to this were either simple reordering of the instructions or adding short delays to allow for the system to 'settle down' before taking measurements.

Assessment of the Platform

Following the end of the term, the students were asked to participate in a class survey. The authors of the survey wanted to explore the impact that the use of the platform had on students' innovative and troubleshooting skills, teamwork, overall understanding of the lecture material, and their perception of mechanical engineering [9]. The survey included standard demographic questions, questions about previous engineering skills, and questions about the Design Competition experience. Out of 120 students enrolled in the class, 105 participated in the survey.

One of the most important results of the survey was that 78% percent of the students thought that participating in the design competition helped them understand what mechanical engineers do in practice. In addition, 69% of the students thought that working with the platform helped them learn about programming, and 61% felt the same way about electrical engineering. In each of the three questions, less than 10% of the students thought that the experience did not improve their skills at all. After comparing the statistics with the students' prior experience it showed that even the more proficient students found the experience worthwhile.

When asked about creativity, 92% of the students agreed that the competition and platform encouraged innovation, and 84% said they were able to think of multiple solutions for the design task. The survey also showed that students thought that the teamwork was important (87%) and that they were able to exchange ideas with other students (69%). In fact, the surveys showed that the Mechatronic platform succeeded in all but one goal: successfully connecting the lecture with the lab material. About 30% of the students thought that lecture helped them with the design competition, and 24% thought that the competition helped them understand the lecture.

There are several explanations for this somewhat surprising result. The most important one lies in the fact that the design competition deals with a mechanical system, as opposed to the system's components discussed in the lecture. For example, students thought that learning about torque in lecture and then later calculating the torque vs. speed curve helped them understand the concept. However, most other concepts that were explained in lecture, even if they were used in the design competition, did not have directly related lab exercises. In other words, students might have had hands-on experiences about some abstract concepts, but did not see a direct connection between the two. So, this integration between lecture and lab was identified as the main area for improvement of the use of Mechatronic platform in ME101. It was encouraging to see that the lab experiences did follow the lecture material, and that strengthening their connection is simply a matter of time.

Conclusion

The introduction of the Mechatronic platform in ME101 helped improve some of the key attributes of this course, including creativity, innovation, teamwork, troubleshooting, and professionalism. More importantly, it brought Mechanical Engineering closer to students by exposing them to a real-world design problem. The use of the platform provided ownership, contextual learning, fun, and hands-on experiences for the students in the class, making it a more worthwhile experience.

Future work will focus on integrating the platform in other Mechanical Engineering courses as a *Platform for Learning*. The experience with this platform will help students to be innovators who are able to integrate their knowledge across many disciplines, preparing them to be effective engineers of the future.

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