AC 2007-150: MECHATRONICS COURSE WITH A TWO-TIERED PROJECT APPROACH

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Mechatronics Course with a Two-tiered Project Approach

Abstract - In this paper, we present a two-tiered project approach. A typical course project requires integration of various technical competencies. When students are assigned such a project, they usually go through a major learning curve. Many of them often fail to complete the project. In the two-tiered approach, student teams are first given small-scale projects that target specific competencies required by the more involved actual class project which is the second tier. After competing the first-tier projects, student teams teach the rest of the class what they learned and share the materials they developed. We present the details of the new approach, provide sample projects and discuss assessment of the projects and the course outcomes.

I. Introduction

Our mechanical engineering curriculum contains four technical electives. Students can choose to take any elective or they can take three of these electives out of a sequence of linked elective courses that constitute an option area. One of these option areas is mechatronics. The mechatronics option has its stem in the two junior level required courses that all students take. These are Mech 304 "Instrumentation and Measurement" and Mech 348 "System Dynamics." After this introduction, students who choose to continue in the mechatronics option take the three electives: Mech 405 "Introduction to Microcontrollers", Mech 467 "Automation" and Mech 468 "Robotics."

The university catalog designation of Mech 405 is a 3-credit, lecture-only course. In the first 8 weeks of the semester, the course is in lecture-only format covering introductory topics including microprocessor architecture, number systems, microcontroller programming in "C", memory maps, registers, digital I/O, analog I/O, timer subsystem, pulse accumulator and hardware interfacing such as switches, motors, LEDs and sensors. In the remaining 7 weeks, the course turns into a laboratory-only format where the class meets in the laboratory during the regularly scheduled lecture hours. In this half of the course, students work on a design project. Successful completion of the design project requires integration of various topics covered in the first half of the course.

In the last two years, the course followed the same format. During these offerings, we observed that the students had major difficulties with the design project. This was primarily because the project required them to master various technical competencies at once in a relatively short period of time. As mechanical engineering students, they faced the challenge of designing a system involving interface electronics and a different set of programming skills to program a microcontroller. Based on these observations, we developed a two-tiered project approach. In the following section, we describe the details. To the best of our knowledge, we are not aware of a similar approach available in the literature.

II. Two-tiered project approach

For the last three years we used the same project. The challenge was to design a machine to sort CD cases. The machine had to work as follows:

CD sorting machine project
1. User will load a stack of CD cases into a stacking guide in the machine. Some cases will contain labels and be opaque; some will be empty and transparent. Presence of the CD cases in the stack must be detected. 2. When the user has placed the cases in the stack, he will press a START button. 3. The machine will then take the cases off the stack one at a time. If a case contains label, the machine will push it into the output stack for full cases. If it is empty, it will push it into the output stack for empty cases. 4. An LCD screen will provide machine status information to the user. Additional design specifications: 1. The machine must fit inside a 1 ft x 1 ft x 1 ft box. 2. It must be constructed from lightweight materials (wood and plastic construction. No metal construction). However, metal parts such as shafts, gears, etc. can be used. 3. The construction must be high quality for future demonstrations. 4. The lowest cost and highest speed design (in sorting 5 opaque and 5 transparent CD cases) will receive 10 bonus points (only one team)

Figure 1. Project requirements for the CD sorting machine.

In the past two offerings of the course we simply assigned the project but observed that the students were struggling with the core technical competencies more than the project itself. We examined the course materials and the project to identify the core technical competencies that the students should feel comfortable with before embarking on the CD sorting machine project. The core technical competencies were identified as:

1. Timer subsystem and programming,
2. Digital I/O interfacing and programming,
3. Analog I/O interfacing and programming, and
4. LCD programming

<u>New approach</u>: We developed a two-tiered project approach where the first-tier consisted of small-scale projects that centered around each core competency required by the second tier which is the main project in the course.

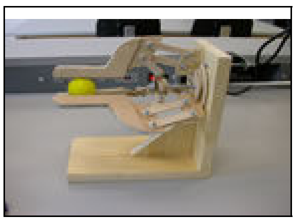
In the first tier, each student group is given four weeks to work on a tier-one project in the laboratory. Then, each group teaches the rest of the class the details of the core competency they worked on. This allows peer-to-peer learning. In this process, each group gave a 25-minute mini-lecture to the class and demonstrated their prototype. The design challenges and programming details were covered in great depth. This approach generated lots of questions and interaction between the presenting group and the rest of the class. Furthermore, all tier-one project materials, including reports, circuit diagrams and code modules, were posted on the course Web site in separate folders for each tier-one project. All students had access to these materials. For example, they could download a program developed by a group addressing a particular competency and use it as a starting point in their tier-two project.

The second-tier is the CD sorting machine project. This project involves all of the core competencies listed above and addressed by the first-tier. Students work in groups to design and build their projects in three weeks. At the end, they demonstrate their machines and compete for the 10 bonus points given to one group for the lowest cost, highest speed design.

II.1. Sample first-tier projects

As mentioned earlier, the first-tier projects are designed to highlight primarily one of the four technical core competencies listed above. However, to create meaningful projects and not just lab experiments, almost all projects also contain a secondary competency. Using small-scale projects as opposed to lab experiments created great excitement among the students. Furthermore, the secondary competencies in each project caused them to consult each other across groups leading to more peer-to-peer interaction and learning. Sample first-tier projects are provided on the next page.

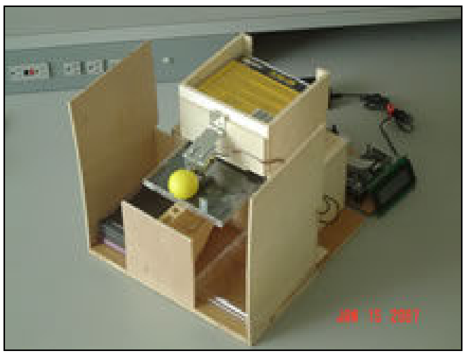
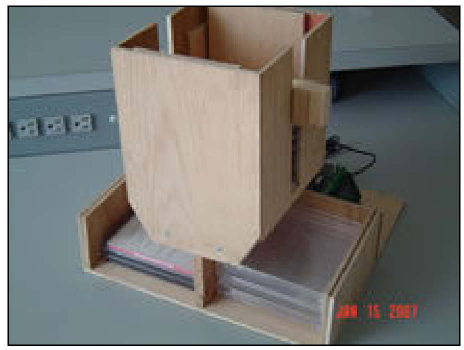
Table 1. Sample first-tier projects.

First-tier project	Details
Digital tachometer 	**Project requirements:** 1) Using an encoder motor speed and rotation direction must be computed. 2) An LCD display should show "Speed " in rpm. Also, it should show "Direction" as CW or CCW. 3) We need to be able to easily attach different motors to the digital tachometer. **Core competencies:** *Primary:* Timer sub-system and programming *Secondary:* LCD programming
Robot hand with R/C servo 	**Project requirements:** 1) The robot hand will have parallel-closing three fingers. All fingers will be operated by one R/C servo. 2) The user will set the desired position using a potentiometer. The controller will then move the fingers to the desired position. **Core competencies:** *Primary:* Timer sub-system and programming *Secondary:* Analog I/O interfacing and programming
Pneumatic robot 	**Project requirements:** 1) The user should be able to move the joints of the robot by pressing push buttons. Cylinder positions should be received as input to the controller. 2) The robot can be programmed to go through a sequence of joint motions. 3) Robot will be assembled from pneumatic valves and cylinders provided to you. **Core competencies:** *Primary:* Digital I/O interfacing and programming *Secondary:* None
Digital thermometer 	**Project requirements:** 1) Use an LM34 precision integrated temperature sensor. Scale the sensor output using an OpAmp circuit to match the A/D range of the microcontroller. 2) The real-time temperature reading should be displayed on the LCD display as " 45 ^{0}F " (with the degree sign and "F" character). **Core competencies:** *Primary:* Analog I/O interfacing and programming Secondary: LCD programming

II.2. Sample second tier projects

In the two-tiered project approach, the second tier project, the CD sorting machine, is the main project for the course. Students worked in groups to design and build their projects in three weeks. At the end, they demonstrated their machines and competed for the 10 bonus points given to one group for the lowest cost, highest speed design. Table 2 shows two sample designs.

Table 2. Sample second-tier projects.

	
CDs are stacked on a belt drive. As a case is pushed out of the stack, a photocell detects if it is empty or not. The golf ball is attached to a motor which spins one way or another to sort the CD case into one of the two silos. The LCD shows the state of the machine in real time.	CDs are stacked on a belt drive underneath the main silo. The drive advances for an inch exposing the edge of a CD case where a photocell detects if the case is empty or not. Then, the belt either continues to rotate in the same direction or reverses to drop the case into one of the two front silos. The LCD shows the state of the machine in real time.
Competencies required: *Timer sub-system:* for motor control signals, *Analog I/O:* for photocell readings, *Digital I/O:* for limit switches and On/Off switch, *LCD:* for machine status display	

II.3. Project assignment and grading

In both tiers the same assignment format has been used. The assignment first specifies the project requirements (Figure 1) and requires the students to think through the typical steps of the design process. Table 3 below is provided on the assignment. The start and the end dates of the project are listed. The deadlines for the intermediate steps are left to each group of students to determine among themselves. They get together and set these deadlines and submit them to the instructor. The team also agrees on a set of project deliverables at each deadline. Each time they miss a deadline, 3 points are deducted from their total project score. This mechanism allows each group to figure out their scheduling conflicts and come to agreements on deadlines and deliverables as a group. It also enforces the professional expectation of meeting the deadlines.

Table 3. Design process deadlines.

Design process components	Description	Deadlines/deliverables
Gantt chart	Project timeline, including milestones and deliverables.	April 3, 2006
Conceptual designs	Conceptual design includes hardware and software concepts (solutions) you generate for the design problem. **Minimum 2 concepts required.**	Use attached form to specify deadline
Concept evaluation and detailed design	Evaluate the conceptual designs and select one to use. Design the details of the hardware and the software algorithm.	Use attached form to specify deadline
Build a prototype	Build a prototype, including hardware, electronic circuits and software.	Use attached form to specify deadline
Testing	Test all functions of the prototype, finalize the product.	Use attached form to specify deadline
Project report and presentation	Write a project report to be shared with others in class. Hold a short lecture to teach the rest of the class the details of your project.	April 24, 2006

Project grading is closely tied to the course outcomes. The course outcomes, in turn, are tied to the program outcomes for ABET assessment. Table 4 provides the project grading details. The same grading approach has been used in both tiers of the projects except for a minor difference. The first-tier projects did not include the "H-4" criterion. The details of assessment are provided in the next section.

Table 4. Project grading details.

Course outcome	Criteria	Points
C-2	Meeting deadlines	12 pts total (3 pts each deadline)
C-4, K-2, K-3	Prototype meets design specs (functioning prototype)	28
C-3	High quality end product with minimal budget	10
D-1	Contribution to team work	5
D-2	Conceptual designs	5
D-3	Working effectively with others	5
G-2	Project report	15 (Content quality: 10 pts; Presentation quality: 5 pts)
G-2	Presentation	10
H-4	Detailed explanation on the economic effectiveness of your design solution, including if and why it is recyclable	10
	TOTAL:	100

III. ABET assessment system

We adopted the ABET "a" through "k" outcomes as our program outcomes. We collect data annually using various tools to assess each of the 11 program outcomes. Figure 2 shows the top-level of the loop.

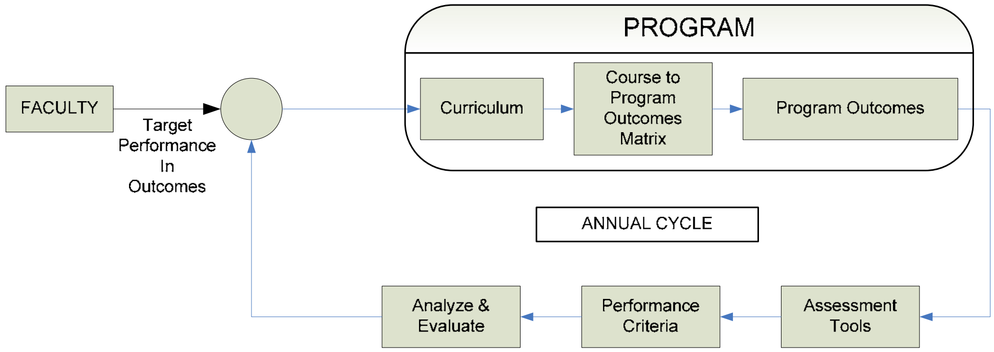


Figure 2. Top-level of the loop for program assessment (only one of the 11 parallel loops are shown).

To assess each outcome, we use performance criteria for that outcome. The performance criteria are measurable attributes describing the performance required to meet an outcome as a program. For example, for program outcome "C" we developed the following four performance criteria:

C. Ability to design and realize thermal and mechanical components, systems, or processes to meet desired needs and realistic constraints.

C-1. Analyzes needs to produce problem definition for thermal or mechanical systems.

C-2. Carries out design process (such as concept generation, modeling, evaluation, iteration) to satisfy project requirements for thermal or mechanical systems.

C-3. Can work within realistic constraints, (such as economical, environmental, social, political, manufacturability, health and safety, ethical, and sustainability) in realizing systems.

C-4. Can build prototypes that meet design specifications.

We have a total of 38 such Performance Criteria for the 11 program outcomes. After many meetings, the faculty finalized a map of Performance Criteria versus courses in the curriculum. This map is the guide for how each course must be designed so that the entire curriculum can demonstrate meeting these criteria, hence the "a" through "k" ABET program outcomes.

Once specific performance criteria are assigned to a course, such as the Mech 405, these criteria are interpreted in the context of that course to generate the course outcomes. The course outcomes describe specific activities that take place in the course addressing the performance criteria assigned to that course. For Mech 405 the course outcomes are listed in Figure 3 on the next page.

In each course, we assess the course outcomes using direct and indirect assessment tools. The data coming from each course for each Performance Criteria, such as the C-3, are then combined to analyze and evaluate level of achievement of each *program* outcome. If any program outcomes are not met at the targeted level, then actions are taken to improve the program.

The students will be able to:

- C-2. Design a system with an embedded microcontroller following a design process.
- C-3. Design a system that will meet realistic constraints such as economical, manufacturability, safety, etc.
- C-4. Build a system prototype that meets design specifications.
- D-1. Contribute to the team work by sharing responsibilities.
- D-2 Create conceptual designs for the team project.
- D-3. Work effectively with others on the team through good interpersonal skills.
- G-2. Deliver project presentations.
- H-4. Explain the impact of their design solution in an economical context.
- J-1. Describe the impact of microcontroller technology in a contemporary issue, such as healthcare, environmental, etc.
- K-2. Interface devices such as switches, relays, DC motors to the microcontroller.
- K-3. Program a microcontroller to provide solutions for practical problems.

Figure 3. Course outcomes for Mech 405.

In the Mech 405 course, the “C” and “K” course outcomes are measured throughout the semester by assigning problems targeting these skills on homework and exams. Furthermore, additional assessment data for “C” and “K” come from the first- and second-tier projects (Table 4). Using this approach each student’s performance on every course outcome is assessed. After analyzing the data, each student is assigned a *score* on the scale of 1 to 5 (highest), indicating their achievement of each course outcome.

The J-1 course outcome was assessed through a research paper assignment. Each student was asked to

1. Research and identify a contemporary issue where microprocessors (not Personal Computers) are used to deal with the issue, and
2. Explain the impact of the microprocessor technology on the issue in hand (the application / solution).

Here the contemporary issue was defined as (1) Recent issues in healthcare, environmental protection, homeland security, electronic voting systems, etc., or (2) Emerging technologies, such as using microprocessors in a new automobile design to eliminate blind spots in the outside rear-view mirrors. Each student submitted a one-page paper and gave a 5-minute PowerPoint presentation to class.

Each group’s CD-sorter project report included a section on the project budget, what measures were taken to reduce cost and how they addressed reducing environmental impact through using recyclable parts. This section of the report was used to assess the H-4 course outcome.

The teamwork outcome “D” was assessed through the instructor’s observations throughout the projects and using peer evaluations by team members.

IV. Results

The two-tiered project approach significantly improved the student confidence and success in the main design project of the course. The students were under much less pressure to complete their first-tier projects compared to a normal course project assignment. This is because we provided slightly more time (4 weeks) than would normally be needed to complete the first-tier projects. Also, the scope of the first-tier projects were scaled down targeting mainly their primary competencies. Each group had a lot of interaction with the instructor and among themselves in the lab throughout the first-tier projects. The relatively relaxed tempo allowed them to explore more "what if" scenarios with their designs and especially with the code they develop.

The parallel approach of the first-tier projects allows more detailed exploration of each core competency in a longer period of time than it would be possible if all first-tier projects were conducted in series by all students. The downside is that each student does not get to work on every project. However, as each group of students taught their findings and shared the details of their projects with the rest of the class, this downside seemed to be greatly eliminated.

By the time the second-tier project was assigned, they felt very confident about their technical skills to tackle this more involved project. Immediately they got started with generating conceptual designs both for the hardware and software for the machine. The software was easy to build since it primarily consisted of integrating modules that were previously developed and shared among the classmates during the first-tier projects. In the past offerings of the course, the students used to spend at least 1-1/2 weeks out of the four weeks struggling to figure out how to get started. It took them long time to conceptually bring together the electronic, software and mechanical sub-systems of their designs. Once started, they always needed a lot of help from the instructor to get them through each step of the project. One lesson we learned was to give more time for the second-tier project. We gave four weeks for the first-tier and three weeks for the second tier projects thinking they could go through the second-tier project faster since they would know what to do having completed the first tier projects. This assumption was partially true in that they knew what to do but it took them longer to construct the physical prototype. The machine was more complicated to build. Also, it was the end of the semester where students were overloaded by projects from other classes and could not spend much time outside the class building this project. Next year, we will give four weeks for each tier.

Table 5 shows the assessment scores (5 highest) for each course outcome computed at the end of the semester. As explained earlier, outcomes were assessed throughout the semester by assigning problems on homework and exams that directly targeted them. Additional data was available from the projects. The table also shows distribution of the scores for each outcome. Overall, the course has been quite successful in meeting its outcomes.

Our program just started collected ABET assessment data in the way explained in Section III. Therefore, we have only one set of such data so far making it hard to compare performance improvement numerically between this year's two-tiered project approach and the previous offerings of the course. However, we observed a significant improvement in the quality and sophistication of the CD-sorter hardware and software designs compared to the last offerings of the course. This year we had 6 teams that designed CD-sorters. All groups successfully completed their projects. In the last two offerings of the course the successful completion rates were 2 out of 4 and 1 out of 3 teams, respectively.

Table 5. Instructor assessment.

Course Outcome	Average (Ave.)	Distribution (%)				
		5	4	3	2	1
C-2	4.8	81%	19%	0%	0%	0%
C-3	4.1	24%	62%	14%	0%	0%
C-4	4.3	38%	52%	10%	0%	0%
D-1	4.6	81%	0%	19%	0%	0%
D-2	4.7	81%	10%	10%	0%	0%
D-3	4.6	81%	5%	5%	10%	0%
G-2	4.6	67%	29%	5%	0%	0%
H-4	3.5	0%	52%	48%	0%	0%
J-1	4.6	81%	5%	10%	0%	5%
K-2	4.8	76%	24%	0%	0%	0%
K-3	4.0	43%	33%	14%	5%	5%

V. Conclusions

In this paper, the details a two-tier project approach is presented. The new approach was implemented in an "Introduction to microcontrollers" course which is part of a three-course mechatronics option in our mechanical engineering program.

In the first tier projects, student teams design and build small mechatronic systems that strengthen their core competencies through hands-on experience. At the end of the first tier, teams teach each other the details of their projects facilitating peer-to-peer learning. The second tier involves a more advanced project that requires using multiple core skills that were just explored in depth in the first tier. In this phase, all teams design CD case sorting machines.

The two-tiered project approach significantly improved the student confidence and success in the main design project of the course. Due to the limited scope and plenty of time available during the first-tier projects, students were able to explore a specific competency more in depth through "what-if" scenarios and extensive discussions with the instructor and among themselves. When the second-tier project was assigned, they could immediately start generating conceptual designs. This was a significant improvement over our experience in the past two offerings of the course. Furthermore, this year all teams successfully completed their designs as opposed to about 50% in the last two offerings.

The Mech 405 course is a lecture-only course. We use half of the semester in lectures. In the remaining half, the class meets in the lab during the lecture hours. The two-tiered project approach is a way to bring lab experience into an otherwise lecture-only course. In this approach, the first-tier projects are different than a pure lab session found in a typical lab course. In many institutions, including ours, typical lab course sessions involve following instructions while examining a sub-system. Although they are scaled-down, the first-tier projects require integration of knowledge, designing and building a prototype. Students found the projects much more exciting than a typical lab session. The two-tiered project approach can be adapted in other lecture-only courses.