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Project-Based Introduction to Engineering – Course Assessment

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Abstract

The School of Engineering and Applied Science at the University of New Haven has a newly developed project-based Introduction to Engineering course. This new course plays a central role in the new ***Multi-Disciplinary Engineering Foundation Spiral*** curriculum as the first semester course for all engineering freshman[1]. An assessment process was developed to determine the effectiveness of this project-based course, specifically with attention towards assessing attitudes, impact on retention, problem-solving and engineering foundation topics. This paper addresses the particular portion of the assessment process for the individual course projects and their contribution to the last two assessment categories.

Introduction

The **EAS107P** ***Introduction to Engineering*** (Project-Based) class uses five major projects to develop an understanding of the engineering disciplines and specific topical content associated with each. The five current projects are: bridge design, solid modeling, mobile robotics, fuel cells, and embedded controllers. The fifth project was not implemented during the pilots but will be implemented in the fall 2004. Each project develops different types of problem-solving skills, conceptual and analytic understanding of engineering disciplines. Additional projects will be added regularly to expand the content areas to cover as many fields of engineering as possible. A detailed description of this class is presented elsewhere[2].

Project assessment is based on a set of objectives and outcomes that are both multi-disciplinary and disciplinary specific. The projects incorporate concepts and terminology necessary for completion and layered upon with further content and applications in later courses. Assessment of student understanding of concepts and terminology measures the degree to which outcomes and objectives are met. For example, in the bridge design project the concepts and terminology include: trusses, resolving of forces (intuitively), tension and compression failure, economic considerations in design, and iterative design for optimization.

For the pilot versions of the course offered in the fall 2003 semester, we chose to assess two major projects with the intent of developing a reasonable methodology that could be applied to all of the EAS107P sections in fall 2004. For each project, specific assessments of related concepts and terminology was done prior to the start and after the completion of the project. The pre-tests helped to establish the student's background, preparation and allow for further tailoring of the projects to better suit the needs of the students. The post-tests attempted to measure the incremental improvements due to the project. Assessments are designed to track individual students and class progress and thus far the results seem promising.

Project-Based Assessment

The use of projects as an alternative to the traditional lecture modality is a widely accepted approach to improve retention and increase student interest[4-6,9-11]. The assessment of these types of courses has followed numerous approaches, including: assessment by Professors only, survey/questionnaires, written student evaluations, student interviews and pre- and post testing. Our interest was in measuring the overall effectiveness of numerous aspects of the course, attitudes of engineering and non-engineering students, impact on retention, academic development due to individual projects, problem solving and team skills. Our focus in this paper is on the role that the projects and course have on the engineering foundation topics. This is critical to our proposed curriculum model that relies on the introductory course to deliver actual gains in conceptual and analytic skills as a basis for future courses.

These gains can be attributed to any number of different course features compared to the traditional "Introduction to Engineering Course": Active-Learning Style, Project-Based Content, Multi-Disciplinary Topics, Strong Emphasis of Team Activities and Numerous Oral Presentations. Thus the testing performed is unable to discern the specific reasons for any improvements, only that they occurred and were chronologically and topically tied to the assessed projects.

The numerous assessments performed during the class included: attitude surveys, pre- and post-project testing, exams, oral presentations, written project reports, individual reports, in-class participation, homework, team self-evaluations and school course evaluations. The pre- and post-testing focused on the project contributions to conceptual understanding and analytic skill development is reported here. These pre- and post-tests were intentionally tried with alternative approaches to structuring the tests so as to qualitatively determine their usefulness. The two pilot courses consisted of engineering and non-engineering students, with an intentionally small cap on enrollments of 18 students each.

Bridge Design Project

The bridge project involved a sequence of activities beginning with a basic understanding of the strength short and long beams in compression and tension; we used stands of spaghetti and demonstrated the increasing strength in compression as the pieces are shortened while no change occurs in tension. Next the students worked with the Johns Hopkins University Virtual Truss Lab to develop a better understanding of the way that trusses distribute the external loads internally and at supports. The students then began an optimized design process using the West Point Bridge Design Program (WPBD), iterating on cost and safety factor for a given set of design constraints. The final step was design realization by fabricating a scale model of the bridge using #8 spaghetti and testing the spaghetti bridge for weight and strength to determine if the scale model failed in a similar way to the WPBD predictions.

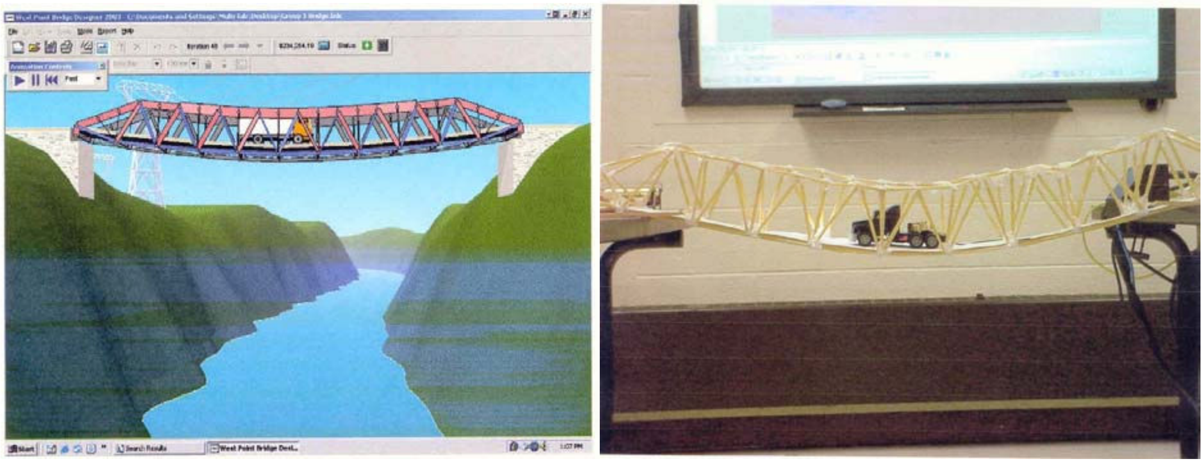

Figure 1: West Point Bridge Designer & Scale Model Undergoing Testing

The project focused on developing numerous problem solving and engineering foundation areas. Some of the expected conceptual gains were:

- Understanding of Trusses (Pratt, Warren, Various Roof Trusses)
- Understanding of the engineering issues surrounding bridge design.
- Distribution of loading based on truss geometry both externally on supports and internally in individual members.
- Ability to balance and resolve forces into perpendicular components (conceptual)
- Developing an appreciation for scale models, limitations of both computational and small-scale models.
- Understanding of the use of modeling software in engineering design.

Some of the analytic skills developed were:

- Computation of safety factors using a hand calculator and Excel
- Determination of buckling and/or compressive strength of members from charts.

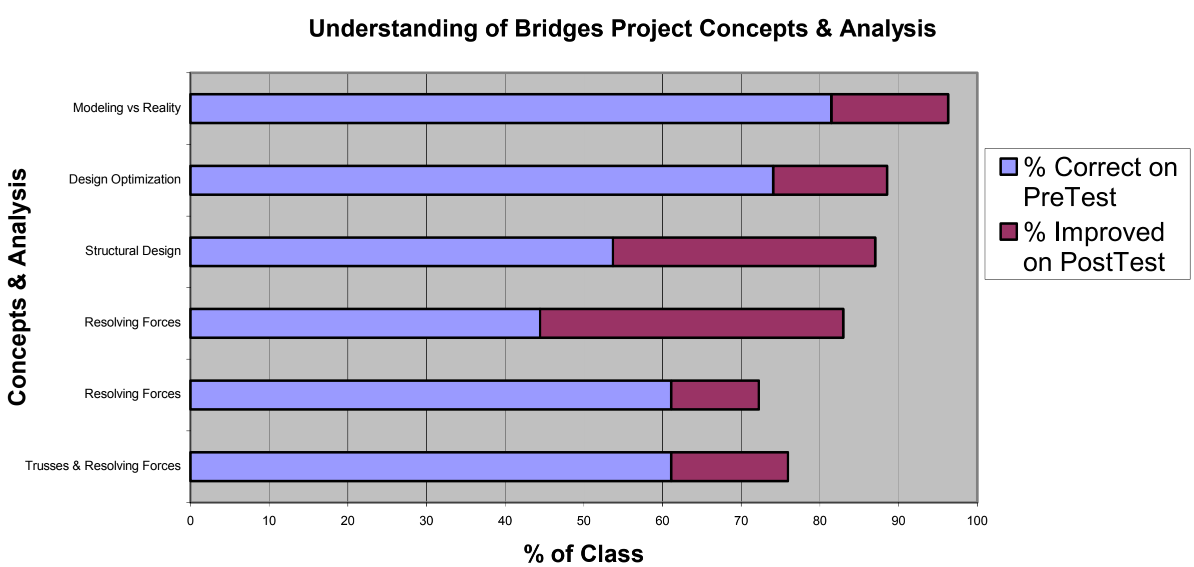

Figure 2: Results from Bridge Design Project Assessments

The first pre- and post-assessment tests for the Bridge Project tested both conceptual and simple analytic skills listed above with questions formatted as multiple choice, short answers and short analytic computations. Each question was directly related to topical content covered in the lectures and during the project. The pre-test and post-tests questions could be classified in a number of different categories shown in Figure 1: Modeling vs. Reality, Design Optimization, Structural Design, Resolving Forces and Trusses & Resolving Forces.

The preliminary results seem to indicate that students have understood and appreciated the essentials of EAS107P, indicating that the course has successfully fulfilled its objectives. Though the results are still very preliminary, the pre-test indicated that the majority of students had an excellent understanding of the role of modeling in engineering design, and the methods and purpose for design optimization. As expected, students lacked a good understanding of how opposing forces balance and how trusses distribute forces applied to them. The post-test seems to show improvement among the classes, with an average improvement of 21% bringing the averages for understanding of key conceptual and analytic topics to over 80%.

Mobile Robotics Design Project

The Mobile Robotics Project introduces students to the field of robotics, engineering mechanics of gears and motors, electrical sensors, and the basics of computer programming. The project objectives were to design a robot for use in search and rescue missions where access was limited to small spaces. The design of the robot had to be as inexpensive as possible due to the likelihood of losing the robot during the mission, while still meeting the mission objectives. The ability of the robot to maneuver through small spaces and around fallen debris would be tested using a randomly assigned 20 by 3 foot obstacle course without moving outside the boundary. Student teams build robots using LEGO robotics kits and programmed it using the RoboLAB programming environment developed by LEGO, National Instruments and Tufts University[12]. Cost was a design criterion, with determination of cost for their robots using a supplied LEGO parts price list.

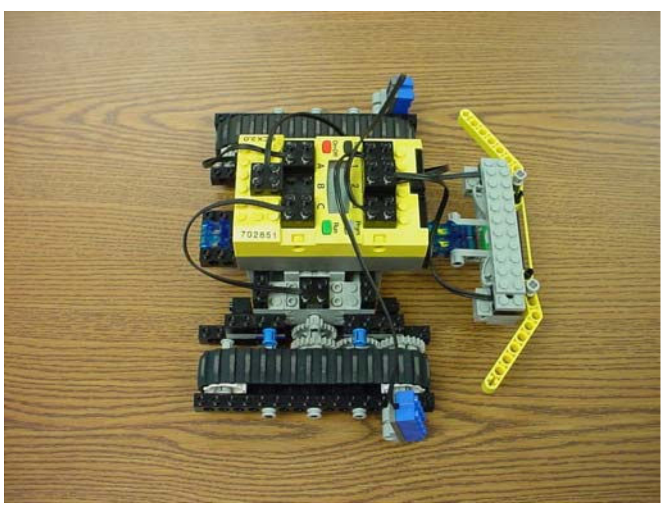

Figure 3: Typical Mobile Robot Design

The robotics project focused on developing numerous problem solving and engineering foundation areas.
Some of the expected conceptual gains were:

- Understanding of the relationship between forces, torque and power.
- Understanding of the gear ratios, speed, forces and torque.
- Understanding of basic programming concepts and constructs: loops, conditional execution, jumping within a program and variables.
- Understanding the basics of embedded controllers
- Understanding the operation and use of sensors (light & touch)

Some of the analytic skills developed were:

- Computation of gear ratios given a specific set of gears or gear trains.
- Calculating the speed, force, torque and power for a given motor attached to a certain gear train.

During the fabrication and testing portion of the projects, students gained a familiarity with the practical application of these concepts while programming the robots to navigate the complicated obstacle course. Each group used an iterative approach to solve the given project. The robot fabrication was straightforward, but the programming and repeated testing illuminated flaws in the logic or poor assumptions about the speed of the robot or time in a particular subroutine. The most common error was for the robots to move outside the boundaries while executing and avoidance routine. This was the most popular project among the different classes.

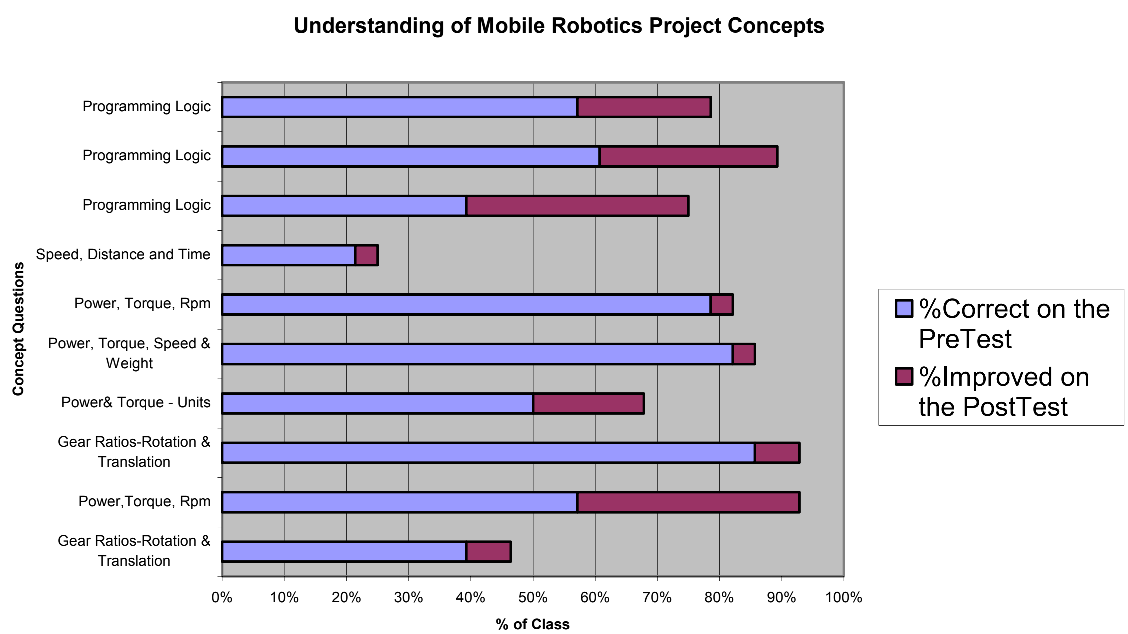

Figure 4: Results from Mobile Robotics Assessments

The pre and post-test assessments of the mobile robotics project were distinctly different from the pre and post-tests of the bridge project. In this set of assessments, we attempted to simplify the comparison of pre and post by testing concepts only and mapping the questions in a one-to-one fashion. The pre-test results indicate a very large variation in understanding that was a bit surprising. It is thought that the questions themselves might have been at fault due to the limited improvement in the post-test results. An assessment of the assessment tool is clearly lacking and an interview of students with a focus on the interpretation of what the questions appear to ask for is clearly required and recommended by numerous authors[8]. This particular assessment seemed much more susceptible to misinterpretation than the bridge assessment. We can speculate that the concepts are less familiar to students in robotics and greater effort needs to be placed up front in the development of clear questions for assessment purposes.

For the questions above, the greatest gains were in the understanding of programming logic, power, torque and rpm. These seem consistent with the degree of emphasis placed on those areas during the project.

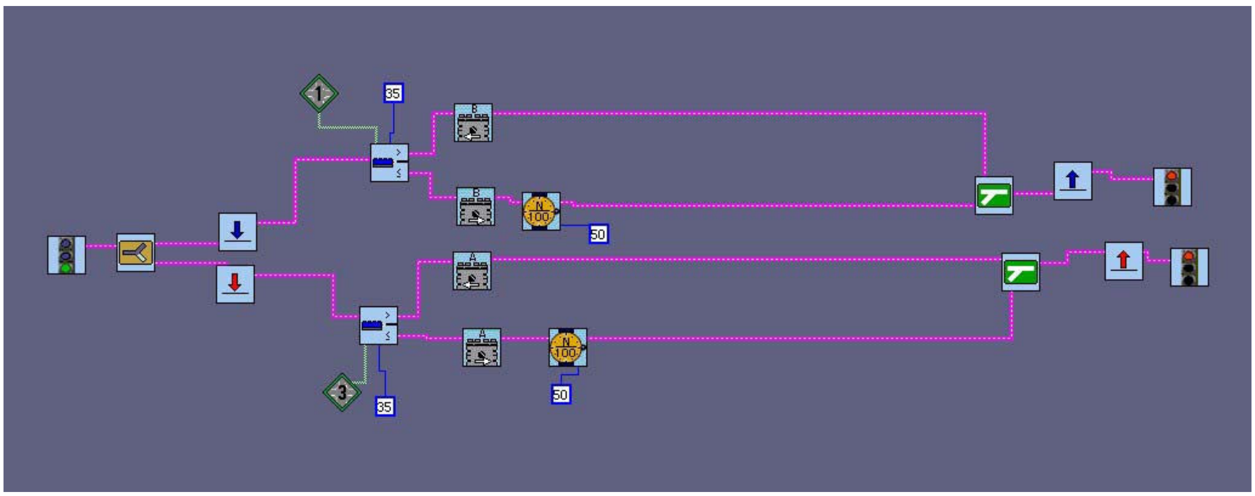

Figure 5: Simplified RoboLab Program Using Light Sensors

Oral Presentation of Projects and Other Assessment Issues

For each of the assessed projects, detailed oral presentations using PowerPoint were required and individual student performance was evaluated with immediate feedback at the end of the oral presentation. Figure 6 shows a modified version of the oral presentation evaluation form used during the class. It was interesting to note that after the first sequence of oral presentations and immediate feedback. For both classes significant improvement in the quality of the presentations was immediate. At this point it is unclear if the immediacy of the assessment, the presence of team members or some outside factor influenced the improvements. Prior to the final paper we will interview some of the students to resolve this question. In addition, every student kept a detailed class notebook or portfolio of: projects, homework assignments, classnotes, oral presentations, which were evaluated for completeness midway through the semester and at the end of the semester.

One of the interesting points about the assessment post-test is the split between measuring real gains and measuring competency. The competency being the deciding factor on assignment of course grades while the gains are the improvements in the student understanding from the start to finish of the project. We were not at all surprised to find a number of students showing no measured gains. Note that these gains may have nothing to do with the specifics of the classroom environment or the pedagogy. The student may be self-motivated and use texts and external resources to gain an understanding of the topics presented. An attitude question or interviews in conjunction with the skill/concept questions is required to determine if the project has truly been effective.

Oral Presentation Assessment Form (Adapted from various sources)					
Student Group:	Project Title:				
Section Number:		Student Performance			
	Max-Score	Mark	John	Luke	Mary
Presented materials are factually correct, clear and unbiased.	10 pts				
The information presented is thorough and sufficient to support the project objectives.	10 pts				
The presentation is well organized and closely reflects the project scope.	10 pts				
The visual aids (photographs, figures, graphics) are of good quality and understandable.	10 pts				
The material presented is relevant to the project.	10 pts				
Interesting examples and/or observations are used where appropriate to keep the audience involved.	10 pts				
Clear speaker, using good grammar, enunciation and eye contact. Good posture and appropriate use of hand gestures.	10 pts				
Overall impression of presentation quality.	10 pts				
Delivered on date assigned.	10 pts				
Delivered within the allotted time.	10 pts				
Total Points:	100				

Figure 6: Oral Presentation Assessment Form

Attitude surveys for different sections of the course, project and non-project based, did not show any statistical significance. Figure 7 summarizes percent improvements in attitude toward engineering based on questionnaires given to all six sections offered fall 2003. Preliminary findings are inconclusive and further evaluation and testing will be needed.

Section #	Pre	Post	% Change
1	3.7	3.8	2%
2	4.1	4.1	2%
3	4.0	4.1	2%
4	3.6	3.7	3%
6	4.4	4.3	-2%
50	4.0	3.9	-1%

Figure 7: Preliminary Attitude Survey Results

There are also some unmeasured components that we would like to include in our further improvements to the assessment process for this class, they include: individual contributions to the construction of the projects, time spend during lab hours, degree to which students lead the teams, accurate measures of contributions to project reports. The last item is perceived to be important for small schools where the students are extremely unwilling to negatively assess a teammate.

Conclusions:

After considerable review of the data collected from the pre and post-test, we can draw some preliminary general and specific conclusions about the assessment of this type of project-based format.

- The use of pre and post-testing during the semester took considerable time away from the available class time. Given the need for as much in-class time for projects as possible it seems reasonable to test students at the beginning and end of the course rather than before and after a major project. While this might cloud the individual contributions from each of the projects, a post-interview of students might be an effective tool to assign contributions that might be unclear to individual projects.

- Analytic and conceptual assessments should be separated to avoid the complex task of determining contributions to conceptual understanding based on partially correct answers to analytic questions or the uncertain relationship between a concept question and an analysis question that imbeds those same concepts. A student may understand a concept but not the analysis methods or perhaps the inverse and be able to apply a simple analytic method without understanding the key concepts. Dr. Daniels has had considerable experience with combined analytic and conceptual testing for the Engineering Materials course that he teaches. Here it seems that administering a lengthy concept test and analytic test similar to those used in Engineering Materials at the beginning of the semester is a possible solution.

- The conceptual testing should follow a modified Foundation Coalition Force Concept Inventory approach. Perhaps components or the actual full suite of concept inventories under development might be used. While analytic questions on a pre-test measure can follow an FE (Fundamentals of Engineering) style to simplify the assessment process effectively.

- The need to assess a grade for a student and the need to assess the gains in conceptual and analytic skills are incompatible. A student's grade is traditionally based on a mastery of the analytic skills and concepts tested or demonstrated during the class. This allows for students who already possess these skills to have very little gains during the class yet still receive a high grade. Anecdotally, this seems a common occurrence yet clearly does not serve the best interests of the student or provide any meaningful information as to the value of the class. To better assess courses both a measure of the individual student gains and the mastery level must be made.

- Student presentation evaluations with immediate feedback were valuable in improving the quality of the presentations but took a considerable amount of time to complete. Since a single detailed feedback session seems effective in improving presentations, a preliminary presentation during lab/office hours with substantive feedback might be preferable to in-class post presentation assessments.

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