AC 2008-2386: LESSONS LEARNED FROM A MULTI-FACETED FRESHMAN DESIGN PROJECT: SOFTWARE DEVELOPMENT, ELECTRONICS, MECHANICAL CONSTRUCTION, SOFTWARE-HARDWARE INTERFACE AND ECONOMICS

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Lessons Learned from a Multi-Faceted Freshman Design Project: Software Development, Electronics, Mechanical Construction, Software-Hardware Interface and Economics

Abstract

In recent publications, we have described the lessons learned from attempts to combine software instruction with the design experience in a freshman Introduction to Engineering course. Initial efforts exposed students to the LabVIEW programming environment as a separate activity from the design experience. The design project was then changed to one in which LabVIEW was used as the software interface for a Hot Wheels Drag Racing Timing and Control System. In this version, freshmen were introduced to LabVIEW as a programming environment and were required to apply this body of knowledge to their design project. At the third iteration, we changed to a more focused instruction in LabVIEW with exercises pertinent to software-hardware interface. We also introduced budgeting by supplying pre-packaged LabVIEW VI's and sub-VIs which could be "purchased" using a limited, predetermined budget of "EGR dollars" with similar options available for the release mechanism and the timing electronics. The availability of the purchase option introduced realistic budget constraints to the design process, with associated penalties or rewards for performance relative to that budget.

We observed that the option of purchasing various components for this project had two major positive effects. The first was an increase in the number of successful projects. The second was thoughtful planning and use of their budgets with provisions of contingency funds for last minute corrections. Assessment using a departmental rubric showed an improvement in attainment of course outcomes related to solution of engineering problems (ABET criterion 3, outcome *e*).

Background

Integration of engineering design experiences into first-year introduction to engineering courses is an important and challenging task, as we try to keep the activities from becoming stale and repetitious, while at the same time keeping the projects at an appropriate level for these new college students and attempting to retain these students in the engineering majors. Tanyel reflected on an initial trial of teaching LabVIEW in the EGR101 class at Geneva College[1]. His recommendations for future revisions to this course included revision of the notes/text which he authored for the course, more sessions taught in the computer laboratory, more use of Blackboard for virtual classroom work, and including other engineering faculty in the design projects.

The first author had taught EGR101 for the previous six years, and returned to teaching this course in Fall 2005. We thought it desirable to continue the LabVIEW component of the course and to create design projects which required the students to apply the LabVIEW concepts they would learn during the computer lab sessions. This decision was based on the recommendations listed above, plus specific student comments on the end-of-course survey asking for "more complicated tasks" using LabVIEW and a general feeling of student confidence in the use of LabVIEW, which seemed desirable to reinforce. The new project component is also consistent with recommendations by Burton and White[2]. They concluded that projects and computing tools should contribute to student interest and success in a freshman design course. These conclusions were based on surveys of freshman and senior students at University of Alaska Fairbanks.

The authors brainstormed for ideas that would be feasible within the context of the course and the available resources at the college and generated three possible design projects. These were

1. Neuroscience measurements for undergraduate biology laboratories[3]
2. Athletic performance measurements, in cooperation with the physical education/track and sports management faculty
3. A measurement/control system using Hot Wheels cars

The third option may seem a bit unusual, but it should be noted that another key feature of EGR101 as taught in 2004 was the use of Hot Wheels cars as incentives (Tanyel, 2005). In considering these options, the following conclusions were reached.

- Project #1 was not suitable for first-year students, but might be a good application for junior or senior students as we establish a core of LabVIEW competency.
- Project #2 was not well-defined, and the equipment needed could become too expensive for a large class.
- Project #3 seemed manageable from a cost and equipment point of view, and would also maintain some of the fun elements previously incorporated in the course.

It also became clear that with a record enrollment in EGR101 we needed to keep the project component manageable, so we chose the third option, which will be explained in detail below.

One goal of this paper is to test the following hypothesis. ***Use of LabVIEW for a real, physical task will improve the students' grasp of LabVIEW and their understanding of the engineering design process.*** Survey results from the class as conducted in 2004 and as modified and refined in 2005-2007 will be used to test this hypothesis.

A second goal is to test the hypothesis that ***improved methods in teaching LabVIEW and basic elements of circuits will lead to improved student confidence.*** Survey results and outcomes assessment rubrics will be used to test this hypothesis.

EGR 101 is an introductory course taken by all students in the engineering program at Geneva College, including those in the Civil, Computer, Electrical and Mechanical engineering concentrations of the ABET accredited BSE and students in the separate Chemical Engineering major. It is also taken by a few non-majors from departments such as Applied Math, Math Education, and Business.

The college catalogue describes EGR 101 as follows:

> Introduction to engineering design and decision-making. Christian world-view applied to engineering. Use of logic, experimental data and design criteria. Project-oriented. First semester.

Until the Fall of 2007, EGR101 met twice weekly for one hour lectures and once weekly for a 3 hour laboratory period. This gave 14 laboratory periods completely dedicated to project work.

This arrangement was changed to one weekly one hour lecture in 2007, with the same number of laboratory meetings, as some of the course content was moved to a freshman seminar course.

The Hot Wheels drag racing project was used for the first time in fall of 2005[4]. The goal of this project was to provide experience in applying Voland's five step design method[5] to a realistic engineering problem, as well as the development of teamwork and communication skills. This particular project was intended to move from a "sterile" computing laboratory knowledge and use of LabVIEW to its practical application within the context of the design tasks.

The initial experience with this design project in 2005 was extremely challenging for the students. They learned a great deal, but the comprehensive nature of the project led to few *fully* successful designs, which contributed to low confidence in their ability to use LabVIEW in practical projects. This paper presents the results of modified forms of the project used in Fall of 2006 and 2007. The recommendations for changes, which were based on student surveys, evaluation of project results, and evaluation of teamwork issues included

1. Earlier introduction of the design project to provide more opportunities for testing
2. Introduction of budgetary constraints and the provision for students to "purchase " various sub-systems to
    a. Reduce overall project workload
    b. Encourage budget-based decisions
3. Structured in-class exercises in data acquisition and control
4. Structured in-class exercises in basic electronics
5. Less formal LabVIEW instruction, with elimination of separate graded LabVIEW exercises
6. Development of new notes and lab exercises to teach LabVIEW skills and concepts in a measurable way, with applications related to sub-problems of the design project

Implementation

Table 1 compares the structure of the weekly laboratory/project activities in 2005, 2006 and 2007. This illustrates most of the changes noted above. In particular, the formal introduction of the project (specifications, etc.) was moved from week 9 to week 4, initial experiences with data acquisition and control began in the second or third week with the simple act of measuring the position of a switch, and students were doing basic electronics demonstrations by week 5 or 6.

The students were assigned to teams for project work. These teams were assigned before the Week 2 activity, so the students could get to know and work with each other early in the semester. Students were assigned to eight teams of four or five students each, using two basic guidelines:

1. Goal of a broad distribution of concentrations within each team – the "ideal" team would include one each of civil, electrical/computer, and mechanical concentration plus one or two additional students.
2. Gender mix – Assign at least two females to any team with female members so female students would not be isolated.

Week	Topic/Focus/Activity		
	2005	2006	2007
1	Introduction to Blackboard	Intro to Blackboard/Personality profile/Intro to LabVIEW	Intro to Blackboard/Personality profile/Intro to LabVIEW
2	Teambuilding exercises	LabVIEW – Communicating with external devices, data types and the case structure	Teambuilding exercises
3	LabVIEW – Introduction/front Panel	LabVIEW – Data types and the case structure	Intro to the design problem LabVIEW – using subVI's to communicate with digital I/O board
4	LabVIEW – Introductory programming	Introduction of the design problem with complete specifications LabVIEW – Timing issues – using loop structures	Machine shop safety – Manufacturing tolerance exercise (Week 4 and 5 activities interchanged for half of the groups)
5	LabVIEW –The case structure and Boolean algebra	Teambuilding exercises	Basic Electronics – LED's, voltage regulators, buffering
6	LabVIEW – Graphical and textual formulas	Data acquisition and control basics (continued), Introduction to LED's and voltage regulators	LabVIEW /basic electronics help by instructors and lab assistants
7	LabVIEW – Loops Conceptual introduction of the design problem	Buffering and Triggering, build-your-own photogate (intro to phototransistors)	LabVIEW – arrays and loops, timing issues
8	LabVIEW – Arrays, clusters, and graphs	Handling arrays of data	Design/testing
9	Specifications for the design problem	Design/testing/etc.	Oral Design Briefing
10	Data acquisition and control basics	Oral progress reports/General project work	Written Progress Report
11	Buffering and triggering	Testing/Construction	Testing/Construction
12	Design review/presentations	Testing/Construction	Testing/Construction
13	Further implementation	Testing/Construction	Testing/Construction
14	Demonstration/Final Report	Demonstration/Final Report	Demonstration/Final Report

Table 1: Weekly laboratory/project activities in 2005 - 2007.

Other aspects, considered informally during team selection, included placing at least one enthusiastic (based on classroom participation) member in each team.

The problem statement distributed to the students was also altered to reflect the new emphasis on budgeting. In 2005 the students were required to build all of their electronics circuits, LabVIEW VIs, and release mechanisms from basic components that were provided. As the end of the project approached these requirements were relaxed and the teams were allowed to use commercially available photogates provided by the instructor and a solenoid-based release mechanism designed by the instructor. In 2006, a budget of 2,000 EGR101 dollars was added to the project. Table 2 lists the items available for "purchase".

Photogate system to indicate when car enters trap area and when car crosses finish line (total of 4 sensors) - returns true except when beam is blocked	EGR$ 500
Release mechanism for starting line (includes own power supply), actuated by a logical true (does not include triggers/switches)	EGR$ 500
LabVIEW SubVI to light Christmas Tree (no handicap)	EGR$ 400
LabVIEW SubVI to light Christmas Tree (handicap)	EGR$ 800
LabVIEW SubVI to release and time a single vehicle	EGR$ 400
LabVIEW SubVI to release and time both vehicles (no handicap)	EGR$ 800
LabVIEW SubVI to release and time both vehicles (handicap)	EGR$ 1,000

Table 2: Purchase options for project budget in 2006, 2007.

This component of the project was created to incorporate cost data into the engineering design process, leading to decisions based on multiple criteria. It was also intended to increase student confidence, since they could focus their original design efforts in areas of strength for their team. There were also provisions for bonus points for coming in under budget, and penalties for cost overruns.

Project Description

The problem statement distributed to the student teams is quoted below.

Hot Wheels Drag Racing Timing and Control System

It has been determined that there is a market for an automated timing system for Hot Wheels drag racing on gravity tracks. Design, build and demonstrate a system to meet the following specific requirements:

1) Design a system to release the two vehicles at times determined by a trigger (throttle) input from a human operator(driver).
2) Design a "Christmas Tree" to let the drivers know when it is legal to release the vehicle and whether they have red-lighted. Use a "Pro Tree" timing sequence for this (see www.nhra.com/basics/basics.html for drag racing rules and terminology). The basic requirements will not include the capability to hold a handicapped race. .

3) Design a timing system to measure elapsed time and vehicle speed. Vehicle speed will be based on a 66 ft (to scale) trap area.
4) The system must be easily attached to the Hot Wheels track without damaging it. Maximum assembly time will be 5 minutes.
5) The complete system must fit within a 16x16x32 cm box before assembly and/or placement. The system must be assembled from the box, if assembly is required, and put in place within the allowed 5 minutes.
6) Systems will be evaluated for accuracy, ease of use, aesthetics of both the hardware and the software, and creativity.
7) An optional (extra credit) weigh-in procedure may be added using a digital balance which has RS-232 communication capabilities.
8) An optional (extra credit) capability to hold a handicapped race may be added.

Allowable resources and materials.

Measurement Computing model USB 1208 data acquisition module with 8 analog inputs, 2 analog outputs, and 16 digital inputs/outputs.
LabVIEW and computer with USB port
Electronic components from a list to be supplied by the instructor. They will include

- Light emitting diodes (LED's) in red, green, and yellow
- Infrared LED's and phototransistors (detectors)
- Buffers for digital outputs
- Signal conditioning for digital inputs
- Switches (SPST)
- Battery compartments (AA) and/or connectors (9 volt)

The instructor will entertain requests for additional materials on an as-needed basis. A public discussion forum will be established on Blackboard to deal with questions related to the rules (clarifications, interpretations, modifications).

Additional Information to be Supplied

Additional information will be supplied. This includes things such as the basis for project grading, project budgeting information, and items available for "purchase".

Reporting and Documentation

All work on this project must be clearly documented in your lab notebooks. You may reference material from other members of your team by name and page number to avoid duplication of effort. Each notebook entry should be dated and signed. You should work only on the right-hand page of the notebook, and should number each page in sequence. You should leave room for a table of contents at the beginning of the project notebook.
Reporting will consist of a mid-project progress report (oral and written) and a final design report, including evaluation of actual performance of the system.

The entire design experience was anchored by the design process as described by Voland[1], which includes the following five steps, allowing for iteration between steps as necessary.

1. Needs assessment

2. Problem Formulation
3. Abstraction and Synthesis
4. Analysis
5. Implementation

Results – General Observations

In Fall 2006, five of the eight student teams had fully functional products at the final demonstration, and in fall 2007 four of ten teams had fully functional products. This means that they could repeatably release and time the cars, as well as detect early starts (red-lighting), while clearly displaying the lighting sequence on their Christmas tree. This compares to one of ten teams with a fully functional product in 2005. Of the remaining teams in 2006 and 2007, only one product was non-functional, while the remainder were mostly functional (typically failed in one area or task).

Four of ten Fall 2006 teams and three of eight fall 2007 teams chose to create all of their own VIs, with the remainder split between buying just the finish VI or buying both the start and finish VIs. The VIs developed in 2007 were of generally higher quality and showed many creative approaches to solving the complex problem of timing simultaneous events.

All of the teams incorporated budget constraints into their design decisions, although often in different ways, ranging from the team that decided not to spend any of their budget in order to maximize points, to teams that made early decisions about how to spend their budget. In the middle were teams that made early decisions to spend money on certain items, but leaving enough reserve to make a last-minute purchase if needed. Two teams did make these last minute purchases after trying to develop their own photogates or their own lighting VI. All teams decided to build their own release mechanisms, which may be telling us something about the difference between how students feel about the visible parts of a system versus the hidden items such as LabVIEW programs and the logic behind them.

Most teams (6 out of 8 in 2006 and 10 out of 10 in 2007) "purchased" the commercial photogates, but two teams successfully built their own photogates. One team even built extra photogates so they could incorporate realistic pre-staging lights as well as a timing trap.

Results – Student Surveys

A survey was used to solicit student evaluations of various aspects of this course. A set of questions covering three main focus areas was distributed and collected on the last day of class, with a 95% response rate. Some of the questions focusing on LabVIEW and the design project were selected from surveys used in the 2004 and 2005 offerings of the class, which included LabVIEW instruction, with no LabVIEW-based design project in 2004 and the previously reported project[1] in 2005. The questions can be seen in Figure 1.

The first two questions show that the students from 2004-2007 have similar previous experience with computers and programming, with some increase in programming experience in the 2007 class. Previous work had found a significant difference (α=0.05 in a Chi-square test) between the responses to questions 3 and 4, and was taken as evidence that the more difficult tasks introduced in the 2005 project led to decreased student confidence, even though they had written more difficult VIs. This trend appears to have improved in the 2006 data, with 57% responding SA or A that they feel confident in programming simple problems in LabVIEW. This response is not significantly different from that in 2004. Responses to question 5 still indicate less appreciation for the exposure to LabVIEW than in 2004.

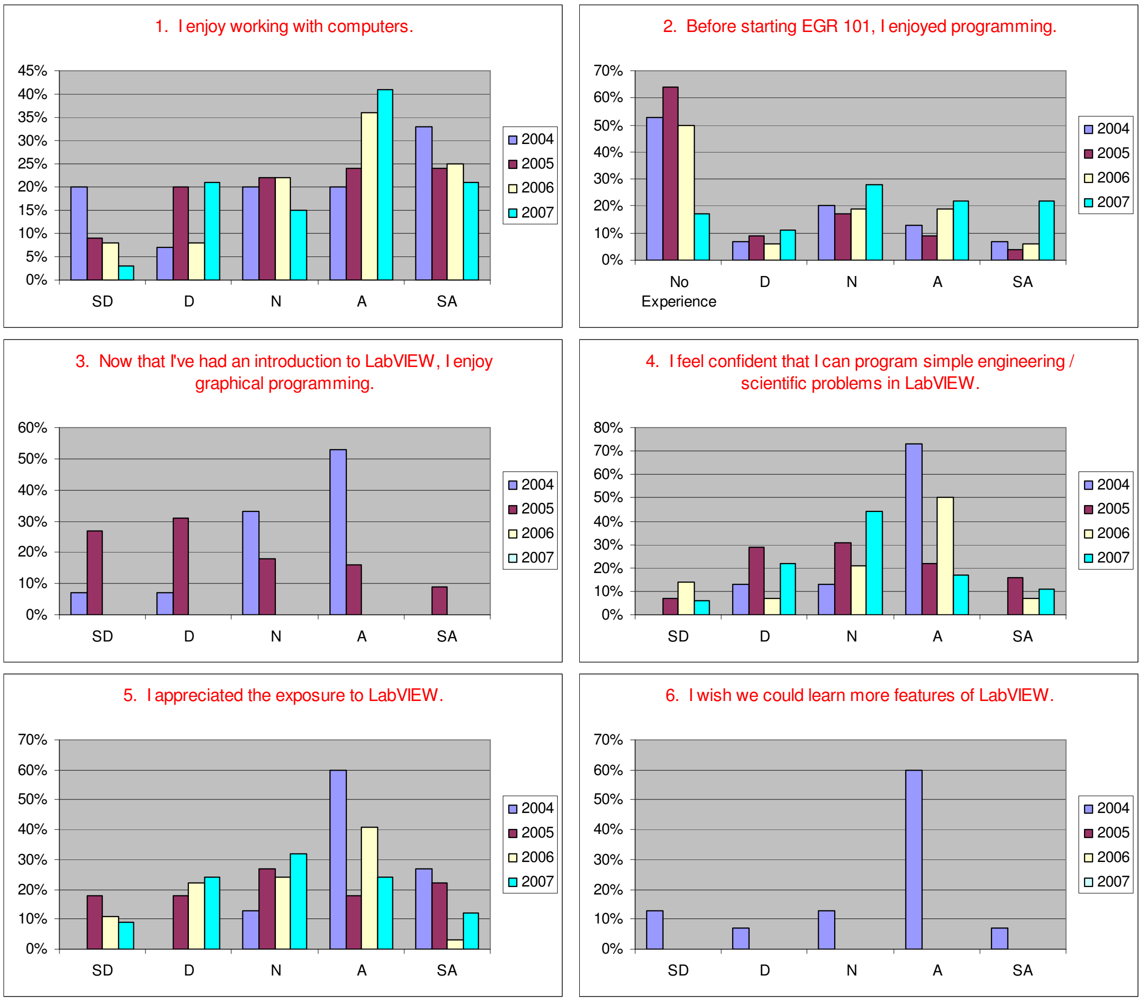

Figure 1: Percentage responses to questions on LabVIEW.

The survey also asked four questions to measure student confidence in implementing and modifying the circuits needed for the course. There was no statistically significant change in responses from 2006 to 2007, although the instructors observed that the 2007 students were more self-sufficient in actually building and testing their circuits. The responses were generally positive, as shown in Figure 2.

There was also the opportunity to provide comments regarding the project on the survey form. For the 2006 class, 17 of 35 surveys had written comments, and 9 of those 17 requested more instruction and time be devoted to LabVIEW. Only 2 suggested more time be spent on electronics. For the 2007 class, 25 of 34 had written comments, 9 or those 25 asked requested more LabVIEW instruction, 8 suggested more instruction in electronics, and 2 requested more instruction in preparing oral and written reports.

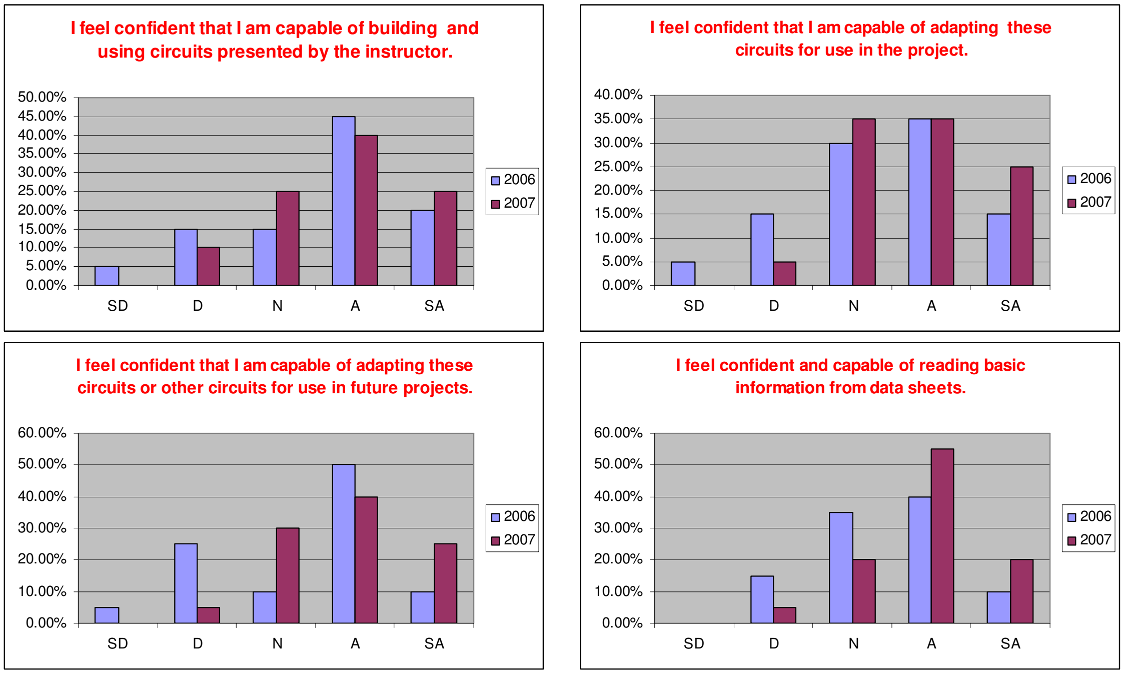

Figure 2: Percentage responses to questions on electronics.

A separate survey used during peer evaluation was used to determine approximate time spent on the project. The average student in 2007 spent 19 hours working with their team and 12 hours working as an individual. The corresponding values for 2006 were 14.5 hours and 10 hours, and for 2005 were 15 hours and 5 hours.

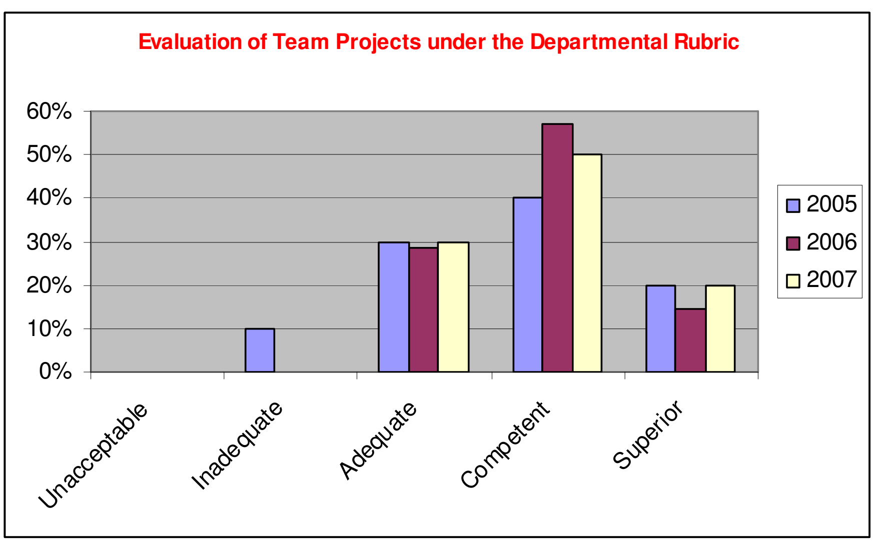

Figure 3: Evaluation of team projects under the departmental rubric. There were 10 teams in 2005 & 2007 and 7 teams in 2006.

Results – Outcome Assessment

A departmental rubric was used to assess accomplishments in the area of "ability to identify, formulate, and solve engineering problems" (ABET criterion 3, outcome *e*). The rubric has five levels – unacceptable, inadequate, adequate, competent, and superior. Evaluation of the team projects found no significant difference from year to year (Figure 3).

A course-specific rubric was used to assess individual student progress on the following course outcomes.

1. The student will be able to use the engineering design process to solve a simple design problem in a team environment.
2. The student will be able to formulate and solve problems using the engineering design methodology.

The rubric was applied to an essay on the final exam. "Draw Voland's representation of the design process and give a specific example of each step from your drag racing design project. Be sure to give plenty of detail about your examples." To be fully successful, the student was required to both recall all steps of the process and relate this to the project.

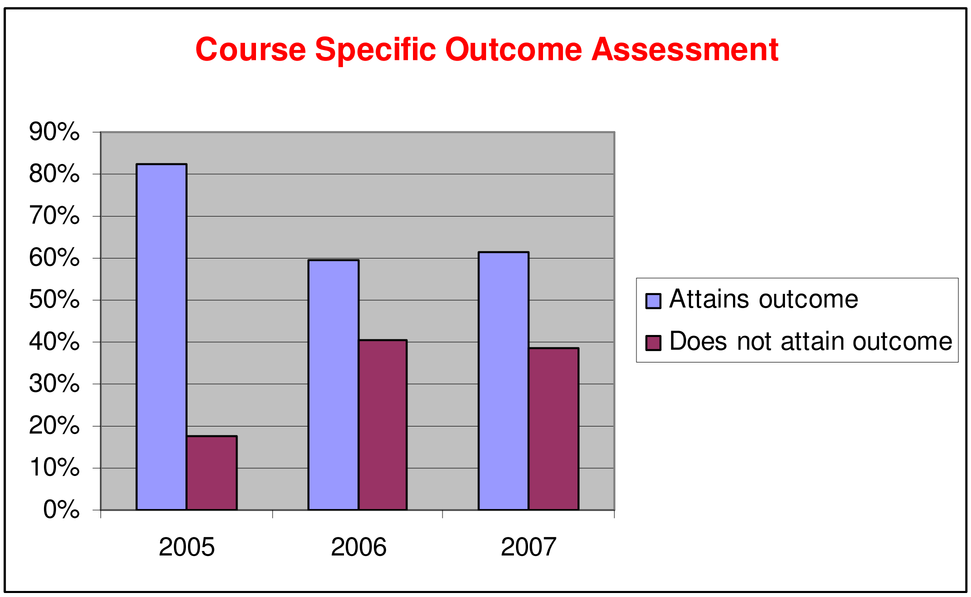

Figure 4: Evaluation of student answers to the final exam question on design process under the course specific rubric.

These results summarized in Figure 4 are somewhat surprising, since new and more forums for progress reports and feedback were introduced in 2006 and 2007 in an effort to improve in this area. In particular, the design reviews were intended to force all members of each design team to talk about the design process in concrete terms, with the goal of improving the connection between the project and the theoretical description of the design process.

Discussion

The results show a general trend toward improvement in the overall design project but not in student confidence with LabVIEW or circuits. In particular, the instructors observed improvement both in overall project performance, team performance, and the details of both electronics and LabVIEW VIs, supporting our hypothesis 1 but not hypothesis 2.

In retrospect, this is not surprising since we spent less instructional time focused on the development of LabVIEW VIs and more time on helping the students integrate existing VIs in 2006 and 2007. The comments on the surveys suggesting more LabVIEW instruction may indicate that we have allowed the pendulum to swing too far away from LabVIEW instruction with these changes.

The option of purchasing various components for this project had several positive effects, as intended. The first was the addition of more realistic budget constraints to the design process, with the associated penalties or rewards for performance relative to that budget. Students used these budget constraints in the decision process to analyze the strengths and weaknesses of various design options. The second was an increase in the number of successful projects, helped in part by the opportunity to spend their budget to address weaknesses in their designs. Only one team chose to purchase nothing, while most teams spent approximately 85% of their budget. The contribution of this process to success was particularly evident for two teams which began the design process with fairly aggressive budget goals of only spending about 50%, but were able to spend some of the additional funds to deal with last-minute problems.

The smaller number of comments requesting additional electronics/circuits instruction and the generally positive response to survey questions in this area seems to indicate that the increased focus on hands-on circuit instruction was successful.

The survey results also indicate some recovery in student confidence using already-developed LabVIEW VIs. This is especially encouraging as we move toward incorporating LabVIEW as our main tool in several junior and senior level courses. It appears that working successfully with the sub-VIs provided by the instructors helped restore student confidence in this area.

The increased flexibility of the project introduced by the ability to purchase some components, combined with earlier introduction of the project, led to more time spent on the project by individuals, with an increase from 5 hours to 10-12 hours. Teams spent approximately the same amount of time (15 hours) as in the past. This fact, combined with the increased levels of success, seems to point toward a more realistic engineering design focus. Students were able to accomplish things on their own and then integrate them into successful working projects.

The most disturbing result is the apparent lack of correlation between student success, as measured by creating successful working products, and student confidence. Completion of a difficult task would be expected to lead to a greater degree of satisfaction and confidence, but that is not evident in the results of the student surveys. This may be because the freshman students don’t have enough experience to gauge their success, believing that smarter people would have accomplished the same thing with less effort. Gender may also play a role, since there is evidence of gender differences for the relation between confidence and success[6] , and there were 3 female students in a class of 37 for 2006, but 9 of 39 in 2007. In any case, the important issue becomes helping these students understand realistic expectations of performance and recognizing their own successes.

Recommendations and Conclusions

The changes to the EGR101 lab in 2006 and 2007 were successful in helping students consider economic aspects of engineering design and resulted in more successful products. The main weaknesses identified by both the faculty and the students involved the decreased focus on LabVIEW instruction, as well as some hardware and software-related problems associated with the changes. Many of those problems were resolved by adapting our instructional approach in the area of electronics, and to some extent in the approach to LabVIEW instruction. To further address these issues we recommend the development of new notes and lab exercises that teach LabVIEW skills and concepts in a measurable way, with applications directly related to sub-problems of the design project. We also recommend creating a workspace dedicated to the freshman laboratory, allowing students to more easily have access to the required computers, supplies, and associated systems.

With these changes we believe the course can move toward improved student application of the engineering design process as well as better retention of and confidence in their abilities with LabVIEW, circuits, and basic mechanisms.

It is also important to address the issue of student confidence, since it may be affecting retention and quality of life for our students. The authors plan to pursue these questions further in cooperation with faculty in the education and psychology departments.

In future work we will also more intentionally address student learning as it relates to Voland's engineering design method. In particular, we will seek methods to bridge the apparent gap between the ability of groups to use and document the methodology, and the inability of many individuals to explain their use of the methodology.

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