Hot Wheels® and LabVIEW Meet at NHRA Division 1 – Take 2

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ABSTRACT

In a recent publication, we described the lessons we learned in committing freshmen to a multi-faceted design project that requires software development, electronics, mechanical construction and software-hardware interface. In our recommendations for future work, we proposed providing some pre-packaged LabVIEW VIs and sub-VIs which could be “purchased” using a predetermined budget of “EGR101 dollars”, with similar options available for the release mechanism and the timing electronics. We argued that such an approach would still require the student teams to integrate all of the subsystems for this project, but would let them focus on building a limited number “from scratch”. This approach would not only enable more of them to have fully operational final products but also help them learn about budgeting issues in engineering design. We have implemented this recommendation in this year’s offering of the course. This paper reports on the changes that this implementation has brought about and the students’ reactions to these changes.

Background

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.

EGR101 meets twice weekly for one hour lectures and once weekly for a 3 hour laboratory period. This gives 14 laboratory periods completely dedicated to project work.

The Hot Wheels drag racing project was used for the first time in fall of 2005¹. The goal of this project was to provide experience in applying Voland’s five step design method² 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.

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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, and this resulted in low confidence in their ability to use LabVIEW in practical projects. This paper presents the results of a modified form of the project used in the fall of 2006. 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

Implementation

Table 1 compares the structure of the weekly laboratory/project activities in 2005 and in 2006. 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 week with the simple act of measuring the position of a switch, and students were doing basic electronics demonstrations by week 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 2 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.

Other aspects considered informally during team selection included placing at least one enthusiastic (based on classroom participation) member in each team.
<table>
<thead>
<tr>
<th>Week</th>
<th>Topic/Focus/Activity</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction to Blackboard</td>
<td>Intro to Blackboard/Personality profile/Intro to LabVIEW</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Teambuilding exercises</td>
<td>LabVIEW – Communicating with external devices, data types and the case structure</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>LabVIEW – Introduction/front Panel</td>
<td>LabVIEW – Data types and the case structure</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>LabVIEW – Introductory programming</td>
<td>Introduction of the design problem with complete specifications LabVIEW – Timing issues – using loop structures</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>LabVIEW – The case structure and Boolean algebra</td>
<td>Teambuilding exercises</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>LabVIEW – Graphical and textual formulas</td>
<td>Data acquisition and control basics (continued), Introduction to LED’s and voltage regulators</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>LabVIEW – Loops Conceptual introduction of the design problem</td>
<td>Buffering and Triggering, build-your-own photogate (intro to phototransistors)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>LabVIEW – Arrays, clusters, and graphs</td>
<td>Handling arrays of data</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Specifications for the design problem</td>
<td>Design/testing/etc.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Data acquisition and control basics</td>
<td>Oral progress reports/General project work</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Buffering and triggering</td>
<td>Testing/Construction</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Design review/presentations</td>
<td>Testing/Construction</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Further implementation</td>
<td>Testing/Construction</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Final testing and demonstration</td>
<td>Demonstration</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Weekly laboratory/project activities in 2005 and 2006.

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 circuits for the Christmas tree and photogates, 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”.

“Proceedings of the Spring 2007 American Society for Engineering Education North Central Section Conference at West Virginia Institute of Technology (WVU Tech), March 30-31 2007”
Table 2: Purchase options for project budget.

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
The following figures show some components of final designs in order to better illustrate the project tasks.

Figure 1. Typical release mechanism. Note also the USB data acquisition device in the background.

Figure 2. Another release mechanism, with a better view of the Christmas tree.
Figure 3. Typical photogate system.

Figure 4. A unique “clamp” release system. The untidy wiring led to big problems with this system.
Results

In fall 2006, five of the eight student teams had fully functional products at the final demonstration. 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 three teams, two had mostly functional products, while one product was non-functional.

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) “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.

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 in 2005. The questions can be seen in Table 3.

Figure 5. A system carefully packed in the official box, proving that it meets the criterion for system
Table 3: Percentage responses to questions on LabVIEW. The first percentage is for the 2004 class, the second is for the 2005 class, and the third is for the 2006 class. (Cells with a “-” indicate that the question was not asked in that year)

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neutral</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I enjoy working with computers.</td>
<td>20</td>
<td>9</td>
<td>8</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>2. Before starting EGR 101, I enjoyed programming.</td>
<td>53</td>
<td>64</td>
<td>50</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>3. Now that I’ve had an introduction to LabVIEW, I enjoy graphical programming.</td>
<td>7</td>
<td>27</td>
<td>-</td>
<td>7</td>
<td>31</td>
</tr>
<tr>
<td>4. I feel confident that I can program simple engineering/scientific problems in LabVIEW.</td>
<td>0</td>
<td>7</td>
<td>14</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>5. I appreciated the exposure to LabVIEW.</td>
<td>0</td>
<td>18</td>
<td>11</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>6. I wish we could learn more features of LabVIEW ...</td>
<td>13</td>
<td>-</td>
<td>-</td>
<td>13</td>
<td>-</td>
</tr>
</tbody>
</table>

The first two questions show that the students from 2004-2006 have similar previous experience with computers and programming. Previous work had found a significant difference ($\alpha=0.05$ 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.

There was also the opportunity to provide comments regarding the project on the survey form. 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.

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

Discussion

The results show a general trend toward improvement in the overall design project but not in student knowledge of or confidence with LabVIEW. 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. The lack of structured LabVIEW assignments for the entire class in the first six lectures would also be expected to lead to this result. The many comments on the
survey suggesting more LabVIEW instruction may indicate that we have allowed the pendulum to swing too far away from LabVIEW instruction with this particular change.

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 the 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 lack 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 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.

Recommendations and Conclusions

The changes to the EGR101 lab in 2006 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. To address these problems 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.

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.
In future work we will also more intentionally address student learning as it relates to Voland’s engineering design method. This will be accomplished using a rubric for outcomes assessment recently developed for general use within the engineering department.

References

1 Shaw, D., Tanyel, M., “Hot Wheels® and LabVIEW Meet at NHRA Division 1”, Proceedings of 2006 ASEE Illinois-Indiana and North Central Joint Section Conference, Indiana University Purdue University, Fort Wayne, Fort Wayne, IN, March 31- April 1, 2006.