Paper ID #19558

Use of a Vertically Integrated Project Team to Develop Hands-On Learning Modules

Prof. Aldo A. Ferri, Georgia Institute of Technology

Al Ferri received his BS degree in Mechanical Engineering from Lehigh University in 1981 and his PhD degree in Mechanical and Aerospace Engineering from Princeton University in 1985. Since 1985, he has been a faculty member in the School of Mechanical Engineering at Georgia Tech, where he now serves as the Associate Chair for Undergraduate Studies. His research areas are in the fields of dynamics, controls, vibrations, and acoustics. He is also active in course and curriculum development. He is a Fellow of the ASME.

Dr. Bonnie H. Ferri, Georgia Institute of Technology

Dr. Bonnie Ferri is a Professor and the Associate Chair for Undergraduate Affairs in the School of Electrical and Computer Engineering at Georgia Tech. She performs research in the areas of active learning, embedded controls and computing, and hands-on education. She received the IEEE Undergraduate Education Award and the Regents Award for the Scholarship of Teaching and Learning. She received her BS in EE from Notre Dame, her MS in ME/AE from Princeton, and her PhD in EE from Georgia Tech.

Robert Lineberg, Georgia Institute of Technology

Robert Lineberg received his BS degree in Mechanical Engineering from Georgia Tech in 2016. Since graduating, he works as a mechanical engineer in the area of space surveillance, expanding from his previous work experience in fabrication and design. While at Georgia Tech he participated in the VIP team on Hands-On Learning for 4 semesters.

Mr. Kevin Peter Ferri, Georgia Institute of Technoloy

Kevin Ferri is a student at Georgia Tech, pursuing a BS degree in Electrical Engineering. He expects to graduate in May of 2018. At Georgia Tech, he has been involved as a lab technician and a teaching assistant for a prototying class. He participated in the VIP team on Hands-On Learning for 4 semesters.

Zachary Crawford, Georgia Institute of Technology

Zachary Crawford is pursuing his bachelors in mechanical engineering and electrical engineering. He is currently enrolled at Georgia Tech and expects to graduate May 2018. He participated in the VIP team on Hands-On Learning for 5 semesters. His fields of interests include embedded systems and electromechanical systems. He is a member of the mechanical engineering honor society, Pi Tau Sigma.

Mr. Justin Tamayo, Georgia Institute of Technology

Justin Tamayo is a student at Georgia Tech, pursuing a BS degree in Computer Engineering. He will graduate in May of 2017, and he will continue his studies at Georgia Tech with a MS degree in Electrical and Computer Engineering. At Georgia Tech, he has been heavily involved in ECE Ambassadors, and he received the ECE Faculty Award for his service to his school's community. He participated in the VIP team on Hands-On Learning for 3 semesters.

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Abstract

This paper describes a mechanism where engineering students simultaneously earn credit for a multidisciplinary project-based course while they act as *partners in education*, designing and building educational experimental platforms to be used by their fellow students. The project course is implemented under a Vertically Integrated Project (VIP) program. This paper highlights three categories of experiments: ones that can be used in a classroom to explore a basic concept within a lecture-based course, ones that can be used as do-it-yourself projects to teach skills in a campus makerspace environment, and ones that can be used as multi-week experiments in a laboratory course. A sample project is given for each category.

1.0 Introduction

Hands On Learning (HOL) is an excellent way to engage and motivate students and to enhance learning of difficult concepts. In engineering education, hands-on learning has traditionally involved instructional labs or studio classes, which are focused on these types of activities. Recently, however, people have started to advocate for the distributed use of mobile, hands-on learning experiments that can be done by students in non-traditional settings [1-3]. For example, students can now do sophisticated experiments with student-owned equipment and can perform the experiments on their own, or in traditional classroom settings. The combination of miniaturization of electronics together with student ownership of measurement equipment and/or smartphones means that there are now many more possibilities for hands-on learning than ever before. A large challenge, however, is to determine where it is most effective to insert these hands-on activities into a course or curriculum.

For the past two years, the authors have co-advised a Vertically-Integrated-Project team on Hands-On Learning (VIP-HOL). The VIP program consists of teams of undergraduate students together with graduate students and faculty advisors who work on projects that have a single theme using a problem-based learning approach [4]. The unique aspect of VIP is that students remain in the program for several semesters, which allows them to transition from “learners to leaders” as they gain experience. The VIP concept was developed by Coyle [5], for which Edward J. Coyle, Leah H. Jamieson, and William C. Oakes received the 2005 Gordon Prize from the NAE.

In Spring 2015, the authors launched their VIP team on HOL, which utilizes *students as partners in education*. Students earn credit for the VIP project course while designing, prototyping, testing, building, and implementing laboratory experiments and projects to be used in classes or in the campus makerspaces. Moreover, the VIP students are able to suggest the course topics, typically ones that they struggled with, for which the projects will be targeted.

2.0 Background on VIP

As mentioned in the introduction, Vertically Integrated Projects grew out of the EPICS program founded at Purdue University in 1995. EPICS, which stands for Engineering Projects in Community Service, is a multidisciplinary program that uses service learning as a mechanism to teach design and other principles. While the projects invariably have an engineering focus, the projects are open to students from a variety of backgrounds and majors. Initially targeting electrical engineering projects, the VIP program has grown to encompass projects, students, and advisors from across campus and has grown to include 24 different universities. The VIP program was started at Georgia Tech in 2009 and has since grown to 41 different teams, on topics ranging from 21st Century Security Challenges, to BioBots, to Smart City Infrastructure, to Sustainable Aquaponic Systems. The central theme of VIP is that students learn very deeply about some topic by doing team-oriented project work. The uniqueness of the program is that students in the VIP program stay with the same project for multiple semesters, gradually gaining experience and competence as time goes by. By their last semester of this long-term involvement, the students are able to both work on the projects themselves and to supervise and lead less experienced newcomers to the team. This structure greatly facilitates the management of the groups, but also creates an incredible learning experience for the students who remain in the team for several semesters.

There have been many publications that discuss the pedagogy of the VIP program. An extensive study reported in [6] presented survey data that showed not only improvements in student knowledge, but also revealed significant increases in students' management and collaborative skills. They also show how each VIP team forms a social network that facilitates project success, and demonstrates that these social networks interact with each other forming much larger networks of learners. In a 2006 publication, Coyle et al. [7] surveyed students on their technical as well as non-technical aspects of their involvement with VIP (at Purdue). Among the responses in the latter category, students reported that they learned teamwork, interpersonal communication, public speaking, and personal responsibility. It is worth noting that students recognize that the VIP program gives them experience in both teamwork *and leadership*. This happens as students take ownership of projects, and evolve from leading smaller groups to larger groups over several semesters. Students also noted and appreciated that the close collaboration between the students and faculty mentors gave them much needed student faculty engagement. This student faculty interaction in curricular and co-curricular activities has been cited as one of the key factors contributing to the success of students [8]. The authors believe that the Hands-On Learning team, with its focus on improving the educational experience for other undergraduates, is particularly effective in developing faculty-student interaction.

3.0 Description of Projects

Several projects are described below that were developed by the VIP HOL team. Some of the projects were developed specifically for ME courses, others are used in ECE courses, and some were developed for use as self-paced learning modules in makerspaces. The generic functional requirements for all the platforms include

- Portable (can be brought into a lecture class and used by students at their desks)

- Low cost (<$50 per unit so that a department can afford to build 25-30 units for use in a classroom by all students simultaneously working in groups)
- Flexible design in order to be used to cover a variety of fundamental concepts in a variety of courses and to make future development possible
- Low learning curve (for instructors and for students)
- Robust design (to withstand novice user interactions)
- Satisfies most of the 13 Feisel and Rosa objectives on laboratory instruction [9]
- Compelling in style and form (to interest and excite students)
- Ease of fabrication (facilitating the adoption by other schools)

The first project described below is an example of a project that can be used in a standard classroom to explore a basic concept in a lecture-based course. The second project is meant for use in a makerspace, and the third project is an experiment in a senior-level laboratory course.

3.1 Table Topper Experiment

An excellent case study on how the VIP-HOL team contributed to learning enhancement occurred in the Spring of 2015. The inaugural group of HOL members consisted of an assortment of 12 ME, CmpE, and EE students. These students were given the challenge of devising a mobile platform to help students in Dynamics courses understand the concepts of centripetal acceleration, and the relations between potential and kinetic energy. In a previous semester, Fall 2014, a device was constructed to allow a small cart to ride on a circular arc. Initially, the cart was equipped with an Arduino and accelerometer, but the limited sample rate resulted in the need for a very large track radius. The track had a nearly 4-foot radius, and the experiment could only be carried out (with difficulty) as a demo in front of the classroom, while students watched. In order for this device to really be practical, it would need a drastic rethinking and redesign.

The HOL members were given instruction in the design process (the ME students had experience in this area due to a sophomore level design class, but the CmpE and EE students had not.) An initial brainstorming session resulted in three different design concepts. Three groups were formed to flesh out these three designs, and to prototype them. When students demonstrated the prototypes two weeks later, the designs were evaluated by their peers, advisors, and two other instructors with a rubric defined along different dimensions including practicality, operation, performance, cost, etc. From the evaluation of the three design concept, a final design emerged, which incorporated many of the attractive features of each design. The final design is shown in Figure 1. One of the key features of the design is its compact dimensions, as well as the fact that it extends upward from the desk/table top; this gave the design its name, the “Table Topper.” The other key feature of the Table Topper was the use of student-owned smartphones to supply the measurement system for quantitative measurements. As shown in Figure 2, the swing arm was designed to accommodate a myRIO or a smartphone as the measurement device. More information on this design may be found in reference [10]; see also, the YouTube video: https://www.youtube.com/watch?v=rrXXwMzwgx8&t=3s

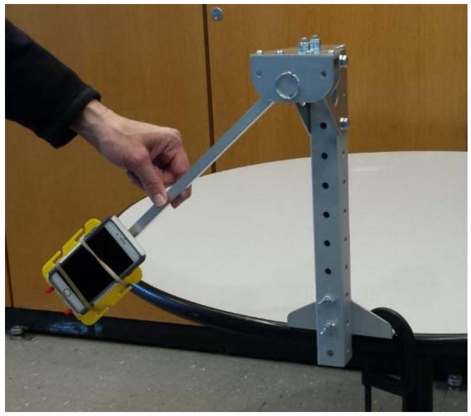

Figure 1: Table topper platform with smartphone

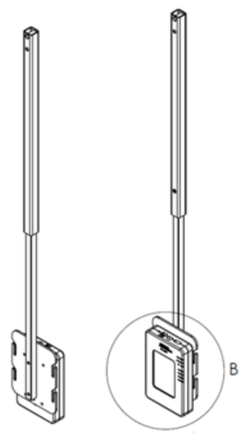

Figure 2: Swing-arm assembly drawing showing attachment to accommodate either a smartphone or a NI myRIO device

One of the ME students (Robert Lineberg) on the VIP HOL team had considerable design and machining experience, and finalized the design. Then, the students utilized the existing makerspace to fabricate 15 replicas of the device. Finally, the devices were deployed in the Spring 2015 semester in a class of 66 students. Notably, the HOL students not only designed and built the devices, but many were also on hand during the classroom experiment to help the students use the device and to overcome problems with the accelerometer apps. Through this procedure, they can directly observe the interaction that the students in the class had with the experimental platform, and then make adjustments to the procedures as needed.

3.2 RC Car Projects for a Makerspace

Georgia Tech is in the process of building an ECE-centric makerspace that complements existing makerspaces that are more ME-oriented. We want to embrace the educational mission of the university in the makerspace, so the space is intended to have very strong support for people who want to learn practical skills and design. As part of the process, we surveyed the ECE students to ascertain what the main focus of the space should be and what their preferences would be on how to learn the skills needed to use the space. The highest ranked responses on the focus of the space were communications (ie, interconnected wireless devices), embedded systems, and electronic prototyping (instrumentation, soldering, hardware integration). The ranking of the responses on the training methods were 1) self-paced tutorials, 2) workshops, 3) one-on-one support with an assistant in the space, and 4) a course devoted to the material.

With these survey results in mind, we challenged the VIP team to come up with a fun, multi-faceted project that could be the basis of several self-paced do-it-yourself (DIY) tutorials that emphasized the desired focus for the space (communications, embedded systems, electronic prototyping). We asked them also to make the project attractive to students from other majors because one of the goals of the makerspace is to support multidisciplinary projects. The team searched existing makerspaces and DIY websites and brainstormed. They wanted something that would be inexpensive for students yet compelling. They came up with the idea of using an off-the-shelf remote controlled (RC) car as the basis for the project. RC cars are relatively inexpensive, portable, and come in a variety of sizes and shapes. Specifically, the students kept the existing chassis and motors on an RC car, but pulled out the controller and replaced it with a microcontroller, see Figure 3. They came up with a number of projects that could be done using the car. These projects are independent and modular, so that students need only choose to work on some of the modules and use completed solutions for other modules. In this manner, they could have a working prototype without having to build the entire system themselves. The modules included

- Introduction to microcontrollers
- Building your own motor controller board
- Microcontrollers 2
- Building an app to control the car
- PID control for autonomous car operation

For each module, the VIP students developed a step-by-step tutorial that not only described the steps but also explained why certain design decisions were made. The "why" is often missing on DIY sites yet is so important when considering engineering education.

Introduction to Microcontrollers: This module is targeted to students who are new to programming, microcontrollers, sensor integration, or just new to the microcontrollers used for the RC car. Two versions of this module were developed, one for an Arduino and the other for the TI Launchpad MSP 432 using Energia. Since Energia is a development environment that mirrors the Arduino IDE, the same code can be run on the Arduino IDE and Energia, with the exception of pin numbers that would need to be selected for the specific processor. This module teaches students how to blink LEDs (both ones on the board and external LEDs), read common sensors, and use a servo motor. The sensors explored in the module are common for small-scale projects such as light, sound, proximity, and force. In addition to making this tutorial available for self-paced activities, the VIP team used this tutorial in a series of workshops on the introduction to microcontrollers where over 200 people attended.

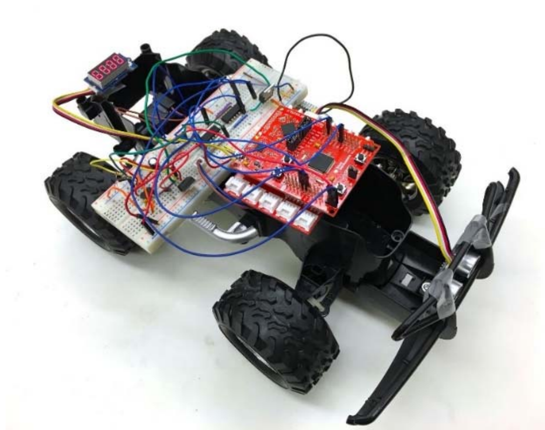

Figure 3: RC Car platform for a multi-faceted DIY project to teach embedded systems in a makerspace.

Motor Controller Board: The RC car needed to have a motor controller board that contained an H-bridge in order to move both forward and backward. These boards are very common to purchase, but the VIP team decided that students might want a cheaper DIY version that could double as a means of teaching electronic prototyping. In addition to the H-bridge, a voltage regulator was added to the board to maintain a constant voltage source even as the battery is discharging. The team designed the board in Figure 4.

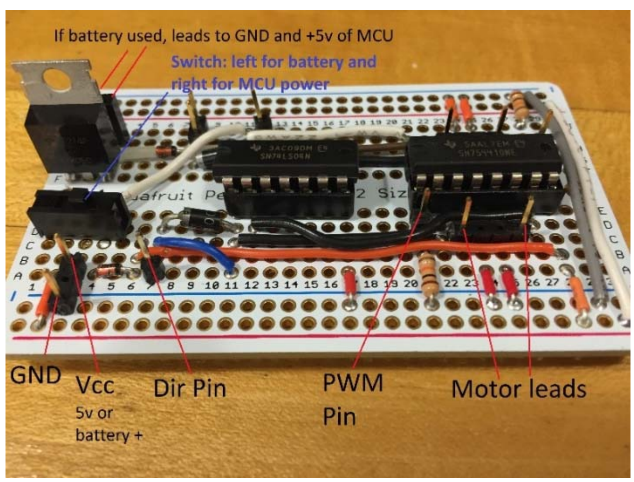

Figure 4: VIP HOL designed motor controller board.

The associated self-paced DIY project on the motor controller board gives the instructions on how to build the circuit using a breadboard. The board shown in Figure 4 is built on a protoboard with through-hole soldering. Several soldering workshops are given on the Georgia Tech campus by students and by ECE staff, so students can convert the breadboarded version to the prototype in Figure 4. Since its development by the VIP students, this particular board has been used extensively for hands-on projects in two courses: one that teaches makerspace skills and the other being a controls course that has take-home projects. The boards work without incidence; in fact, at least some students preferred using this simple board rather than a commercial motor control board. In particular, several of these boards were missing after the first project in the controls class, so some of the students were given a commercial board for the next project. They had difficulties interpreting the datasheets and figuring out how to connect the commercial board, so they asked for the parts in the above figure and just built and used bread-boarded versions of the design.

Microcontrollers 2: This tutorial is a follow-on to the introduction on microcontrollers. It uses the motor controller boards, an encoder, and a DC motor to show students how to build their own servo motor.

Smart Phone App Design: In order to teach wireless communications and app design, the VIP team designed an app for the smart phone that replaced the remote controller that came with the RC car. In this new case, this design became an Internet of Things (IoT) project. A WiFi module was added to the microcontroller on the RC car, so that students can directly control the car's motion through their phone.

RC Car PID Control: In order to teach PID control and how to use it in a real project, the students decided to put a proximity sensor on the front of the RC car and then attempt to control the car to track a set distance from an object in front of the car, nominally 10 inches. This project builds on the Microcontroller 2 project, where students learn how to build a servo (in the RC car project, the loop is closed around the proximity sensor rather than an encoder). The students wrote a tutorial that showed students how to design the PID controller for this application, and included information about PID control decisions. This particular project is an example of autonomous operation of the RC car.

3.3 Treadmill Project

In the Summer of 2015, the HOL team launched an ambitious project to build a multi-week controls experiment for the senior ME instructional laboratory. The senior laboratory is a 3-credit hour course with two hours of lecture and three hours of lab each week. The lab consisted of approximately 6 experiments on mechanical systems and 6 experiments on thermal systems. The pre-requisite laboratory class is a measurements and instrumentation lab that focuses on sensors, transducers, data acquisition, and error analysis. The senior laboratory, in contrast, is designed to tie experimental techniques to mechanical engineering systems. The weekly experiments are supported by one or two lectures in which the theory and models for the system are reviewed. The students perform a scripted, step-by-step procedure, and then compare their experimental results to the theoretical predictions. Two of the weekly labs utilized a DC motor and flywheel supplied via the Quanser (QET) DC Motor Trainer board [11]. The objective of the first week was to model the motor using time-domain and frequency-domain system identification techniques. Then, the next week involved the closed loop position control of the motor. The lab is fairly straightforward and is a mainstay of many undergraduate mechanical engineering curricula. Although the Quanser QET is a very good product, one of the problems with the lab was that students found it to be uninspiring and they could not see the direct applicability of the concepts to engineering tasks.

To address the student perception issues, a decision was made to revise the structure of the senior lab from one with weekly, un-connected experiments, to one in which there were smaller number of multi-week experiences. The multi-week experiments would be scaffolded so that each week built on the last, culminating with a fairly sophisticated investigation of a system having multiple components. Thus, a laboratory course that featured 12 experiments over one semester, would be replaced with one involving 3 in-depth experiences, with time for students to reflect and, when necessary, redo experiments. The multi-week experiments would be spaced with one week in between to give time for written and oral presentations of findings.

The HOL group considered the DC motor experiment and agreed that it lacked imagination. Instead of a motor and a flywheel, why not consider an RC car? Angular commands to a motor could be replaced with the task of an RC car maintaining a set distance from an object. Instead of an experiment that focused on turning a flywheel, why not have an experiment in which the motor drove a conveyor belt? Finally, after studying the RC car and the conveyor belt separately, the final week could involve placing the RC car on the conveyor belt, to examine how well the RC car could maintain its position objective while running on a track of variable speed. While, in theory, speed control of a conveyor belt is the same as speed control of a motor/flywheel, the HOL students agreed that the former was more interesting and original. Furthermore, it was much more obvious that the conveyor belt had direct application to moving products through a factory, or in other automated production systems. PID control of an RC car's position is mathematically equivalent to angular position control of the motor/flywheel, but the position control of the RC car on and off the conveyor belt has direct relevance to technologies such as mobile robots and self-driving cars. The fact that students would spend 3 to 4 weeks with the systems also allowed for a greater depth of experience with the theory and practice of control theory. It allows for the just-in-time instruction in programming, modeling of electromechanical systems, and real-time control.

To tackle this effort, students would need to customize an RC car, replacing the remote control with a closed-loop controller. Their previous experience described above gave them a good background on how to do this. The choices of embedded processor, power, choice of car, etc all would involve design, prototyping, and redesign. They would also need to design a conveyor belt from scratch, that would be compact enough to sit comfortably on a lab bench, but would have the ability to command and control speed, and to adjust the slope (grade) of the surface.

A project of this magnitude would require more than one semester, and would involve a multidisciplinary team of students with skills in mechanical design and fabrication, electronics, and computer programming. The long-term nature of the project made it ideal for the VIP structure. Also, the decomposition into what we termed "Team RC Car" and "Team Treadmill," gave opportunities for leadership, and for integration of engineering design. Were it not for the VIP structure, this endeavor could not be successful.

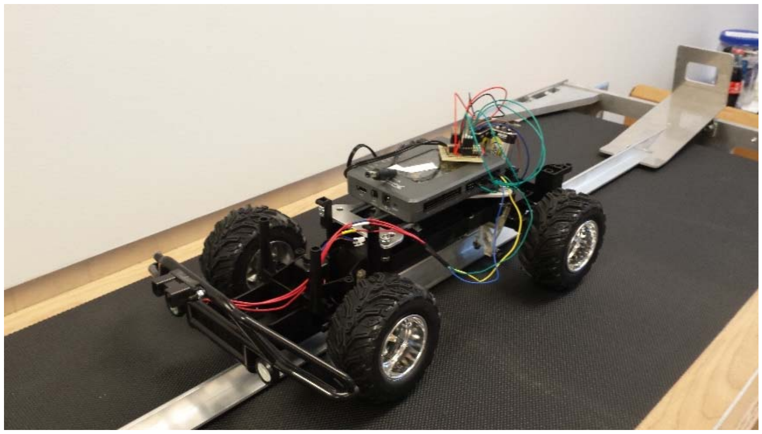

Figure 5: RC Car with myRIO

Team RC Car: From the standpoint of the needs of the senior lab, the size of the car needed to be small-enough to fit comfortably on the treadmill/conveyor-belt, but large enough to act as a platform for the microprocessor, batteries, and electronics. See Figure 5. One of the first decisions that needed to be made was which type of microprocessor to use. On the one hand, use of a microprocessor such as the Arduino, Raspberry Pi, or TI Launchpad (MSP432) was attractive from a cost and weight standpoint. However, given that the project was intended for a mechanical engineering senior laboratory, it was decided that the overhead of having to teach rudimentary coding within the context of a 3 or 4 week lab would be prohibitive. The alternative processor that was considered was the NI myRIO, programmed using LabView. The myRIO was already being used in the sophomore-level design course, and in the junior-level measurement and instrumentation class, so the learning curve for programming the myRIO was expected to be much less. The myRIO also comes in a hardened case, which includes convenient I/O. However, the myRIO was also more expensive and had more weight than the TI Launchpad, so there were definite plusses and minuses to the final choice.

The RC car itself required several important modifications that teams of VIP students tackled over three semesters starting with the car that was modified for the makerspace project. Those modified cars included a proximity sensor mounted on the front of the car, a myRIO on board, the motor controller board and suitable batteries for the application. Finally, students needed to create a PID controller in LabView, with provisions for easy adjustment of gains, and with a front panel that included diagnostics and performance curves.

Team Treadmill: The conveyor belt was a much more challenging part of the project due to the complexity of the mechanical and structural assembly. Given the resemblance to a treadmill, the students dubbed their team "Team Treadmill." There were several design specifications and user demands that were first determined through discussions between the faculty advisors and the students: First, the treadmill must be small enough to comfortably sit on top of the existing lab benches in the senior lab. The track portion of the treadmill also needed to be long enough and wide enough to accommodate the RC car. Since the RC car with an un-tuned autonomous controller was anticipated to have +/- 10 inches of transient excursion in the longitudinal direction, the track length needed to be at least 20 inches longer than the RC car itself. These requirements led to target dimensions of 48 inches of overall length (35 inches of track length), 20 inches of width (12 inches of track width), and height of 12 inches (when stowed.) Another design requirement was the desire to be able to raise or incline the ramp while the car was operating, to observe the ability of the car to operate robustly in the presence of changes in a bias disturbance. Figures 6 and 7 show the treadmill design in the stowed and ramp-inclined configuration.

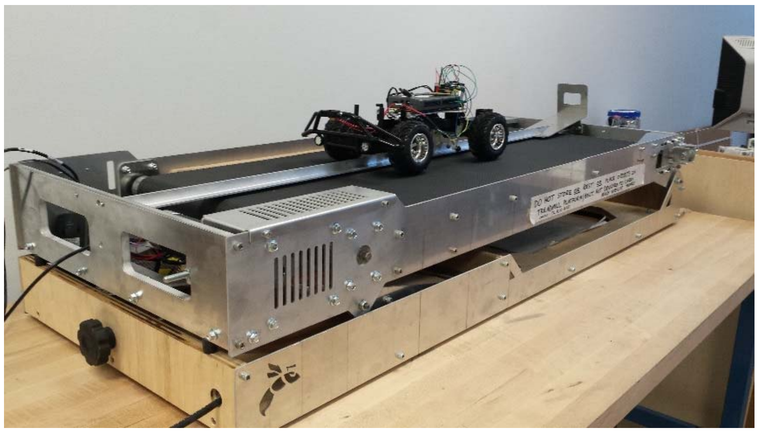

Figure 6: Treadmill with RC car

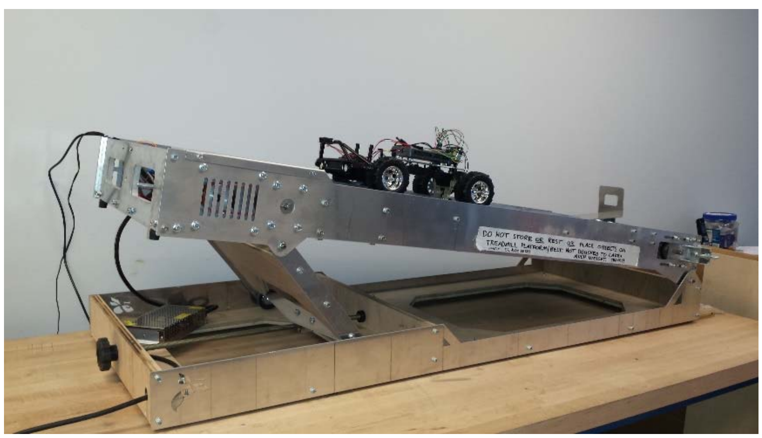

Figure 7: Treadmill exhibiting ramp incline feature

In addition to geometry, the treadmill needed to have a speed control system that was open and accessible to students who would program a speed control system. Students needed to determine the motor torque/power requirements and drive mechanism for the conveyor belt. In the end, the students opted for a Midwest Motion Products (MMP) 12 Volt DC Motor with 78 Watts and 40 ounce-inch of continuous torque (280 ounce-inch peak torque). The motor comes equipped with a planetary gearbox, which the students connected to a drive pulley using a belt. In addition, the motor had an encoder for angular position measurement. Figure 8 shows a close-up of the motor drive system.

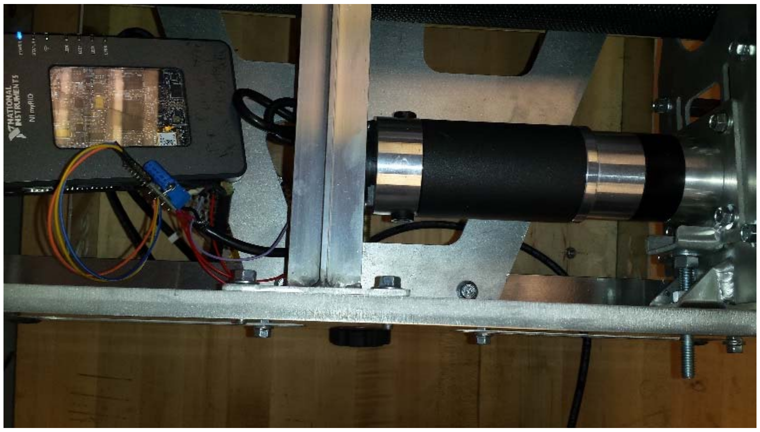

Figure 8. Close-up of motor/encoder and pulley drive system

The students designed all of the parts, fabricated them in the student-run maker space, and succeeded in creating a constant-speed prototype for initial testing. A video of the operation of this system is available here [https://www.youtube.com/watch?v=GDO1RCjl5qM]. The initial trials worked quite well, but it quickly became apparent that the lateral movement of the RC car was too great; with the controller only addressing the longitudinal position of the car, the car would slowly drift to one edge or the other. Also, the forward and backward excursions of the car were mostly within the target +/- 10 inch range, but on rare occasions, the transient excursions became alarmingly large. Rather than add a lateral controller to the RC car, the students decided to design a central guide that could keep the vehicle on the belt centerline. The guide also was configured so that if the vehicle moved forward or backward too far, the car would be encounter a ramp that lifted the drive wheels off of the conveyor belt. A close-up showing the 3D-printed guide straddling the aluminum track is shown in Figure 9.

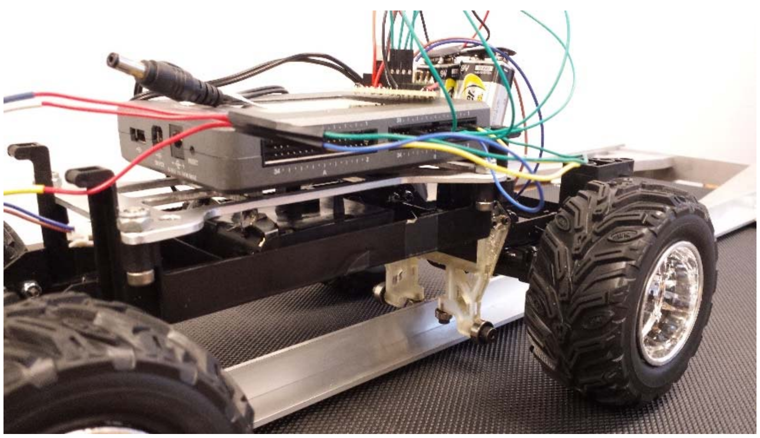

Figure 9: Close up of RC car showing lateral guide and track

Finally, another team of students designed a speed control system for the treadmill. This secondary controller used a separate myRIO with a PI controller implemented in LabView. Since the power level of the treadmill motor was significant, a commercial motor control circuit was used to interface the microcontroller, power supply, and motor.

4.0 Assessment Results

There are two types of learning outcomes that we expect from this project: one relates to the VIP students and the other to the students in courses that use the VIP-designed platforms. The purposes of the VIP program are for students to learn how to design products, learn professional skills, have a deep and long-term experience with a project, and to learn leadership skills. For the HOL team, two students stayed for five terms, one student stayed for four terms, one student stayed with the program for three terms while becoming the leaders of their sub-groups. Eight other students stayed for two terms, and twenty-two have been in the group for one semester including ten who just began in the current semester. In all of these cases, the students gained experience and were able to contribute to the team both technically and through leadership. Students must complete peer evaluations for the students in their sub-groups, where a sub-group works on a particular project within the Hands-On Learning theme. Studies are currently being conducted on the peer evaluations.

Other assessment studies evaluated both student performance and student attitude and confidence in the course topics as they relate to the experiments. For example, a study was performed on the hands-on learning in-class experiments developed for a circuits class under a previous NSF grant. These results validate the efficacy of our hands-on learning approach and demonstrates how the techniques help certain groups of students learn concepts better. Students were given basic concept questions on the final exam, where some of the concepts were related to the experiments and others were not. The gain in performance on the experiment-related concept questions versus the questions on concepts not related to the experiments is shown in Table 1; an ANOVA analysis on the data indicated statistical significance with p-values < 0.09. The performance gains due to the in-class experiments is largest for the middle range of students, indicating generally that B and C students are impacted the most from the experiments.

Table 1: Results of a concept test where performance improvement indicts the scores on concept questions related to the experiments compared to concepts not related to the experiments.

Overall Score	Performance Improvement
16-20 (N=48)	7.9%
11-15 (N=151)	20.4%
6-10 (N=120)	11.4%
0-5 (N=33)	Results not statistically significant, p-value = 0.7

Students were also given a survey at the beginning and at the end of the course asking them to rate, on a scale of 1-4, how well they understand each of the topics in the course. The topics were grouped into those that were reinforced by the experiments and those topics that were not related to the experiments. The survey essentially gives the confidence level of the students on each topic. The median gains in confidence for topics reinforced by the experiments (I) and topics not related to the experiments (II) for all students and students grouped by final grade achieved is shown in Table 2 where a Mann-Whitney analysis shows statistical significance with p-value < 0.09. The students showed significantly larger gains in confidence from the beginning to the end of the term for topics that were reinforced by the experiments. More details of this study on the circuits course are given in [3].

A study was done in a Dynamics class comparing the use of the large cart demo used in Fall 2014 with the Table Topper, shown in Figure 1, used in Spring 2015. Figures 10-12 show the results of surveys that examine student attitude at the end of those two semesters. Both semesters were offered by the same instructor using the same course format. The only difference was in the way that the experiments were conducted. In both semesters, the students performed the same analysis on the data, but in Fall 2014 the data was collected by a professor performing the experiment in front of the classroom while in Spring 2015 the students did the experiment themselves on the Table Toppers in groups of 3-4. Figure 10 shows the results of post surveys in both terms asking students to rate the importance of various components of the course in terms of learning the course material, where 1 was the lowest rating and 6 was the highest. There is a significant improvement in the way students perceived the importance of the experiments in learning the course material when they did the experiments themselves.

Table 2: Gains in self-reported competence on course topics with Category I are the topics that were reinforced by experiments and Category II are topics that are not related to the experiments.

Students	I (experiments)	II (no experiment)
All (N=251)	28%	13%
A (N=119)	35%	25%
B (N=80)	29%	13%
C, D, &F (N=52)	Results not statistically significant, with p-value > 0.2	

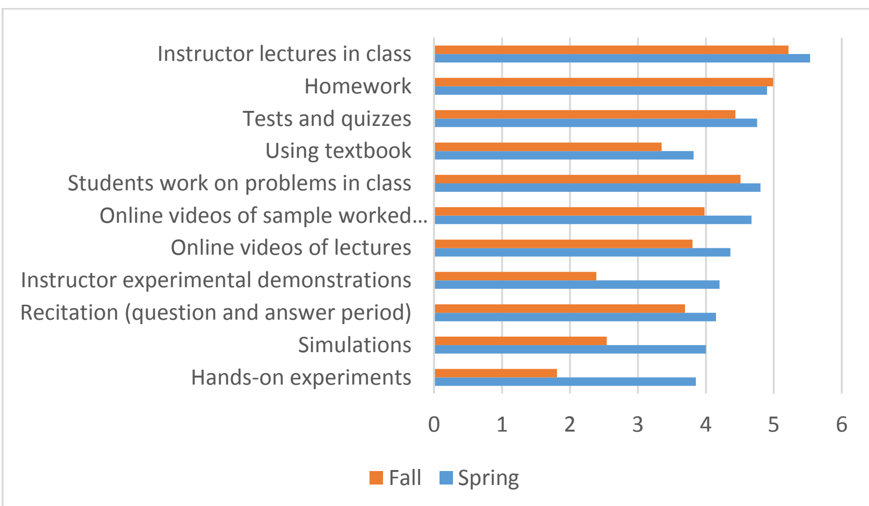

Figure 10: Comparison of post survey results from Fall 2014 and Spring 2015 showing students ratings of the importance of different course instructional components, where 6 is the highest rating. N = 65 and 61, for Fall and Spring, respectively [10].

In the same survey, students were asked an open-ended question on their suggestions to improve the experiments in the course. These comments were aggregated into three categories shown in Figure 11: eliminate them, improve them, and increase the number of them. In Fall 2014, none of the students wanted to increase the number of the experiments in the class and 16% wanted to eliminate them. Of the 83% of the comments in the "improve them" category, the largest suggestion was that the experiments be made more hands-on. It should be noted that most of the students who took this class had already completed the circuits course described above where the experiments were hands-on. When the Table Topper was used, the number of students who wanted to increase the number of experiments in the class jumped to 77% and the number who wanted to eliminate them dropped to 8%. This indicates the preference towards students wanting to do the experiments themselves and the fact that the students responded well to the design of the Table Topper.

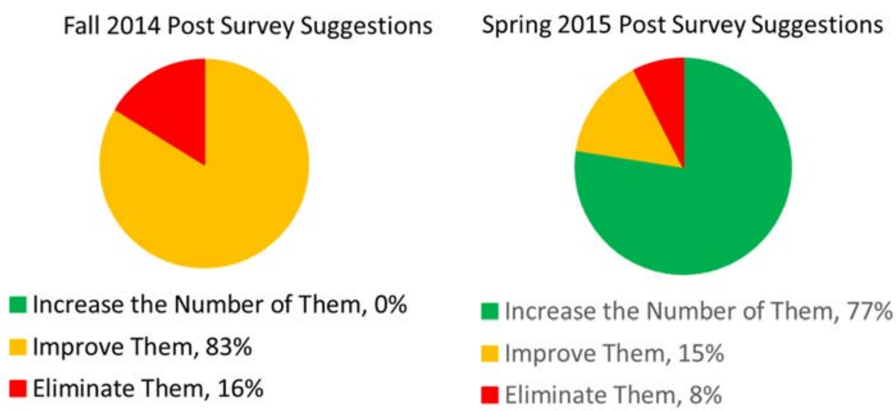

Figure 11: Comparison of student results before the Table Topper (Fall 2014) and with the Table Topper (Spring 2015).

To perform a deeper analysis on the benefits of the experiments, students in the Spring 2015 Dynamics 2015 were asked to rate the impact of the experiments in terms of several possible benefits, shown in Figure 12, on a scale of 1-5 with 5 being the highest rating. One of the highly-rated benefits was the transfer of knowledge/skills to problems outside of the course. Also valued, was the opportunity to work collaboratively with fellow students and the ability to think about dynamics problems graphically and pictorially.

4.0 Concluding Remarks

In the present semester, students are finalizing the RC car design and the treadmill design for pilot testing later this semester in the ME senior lab course. For the most part, the physical system has been designed, but small modifications are necessary to ensure safe operation when the system becomes part of the senior lab. The VIP students are also conducting a human-factors analysis of the design to anticipate how students will interact with the design, and how easy it will be for them to carry out the lab. As envisioned, the first week of the experiment will involve students coding their own PI controller for speed control of the belt. The students will also subject the treadmill to step commands and sinusoidal commands to determine a simple first-order model of the system. The second week, they will design a PID controller for the RC car, but they will test the performance with the car on the floor and test the performance using

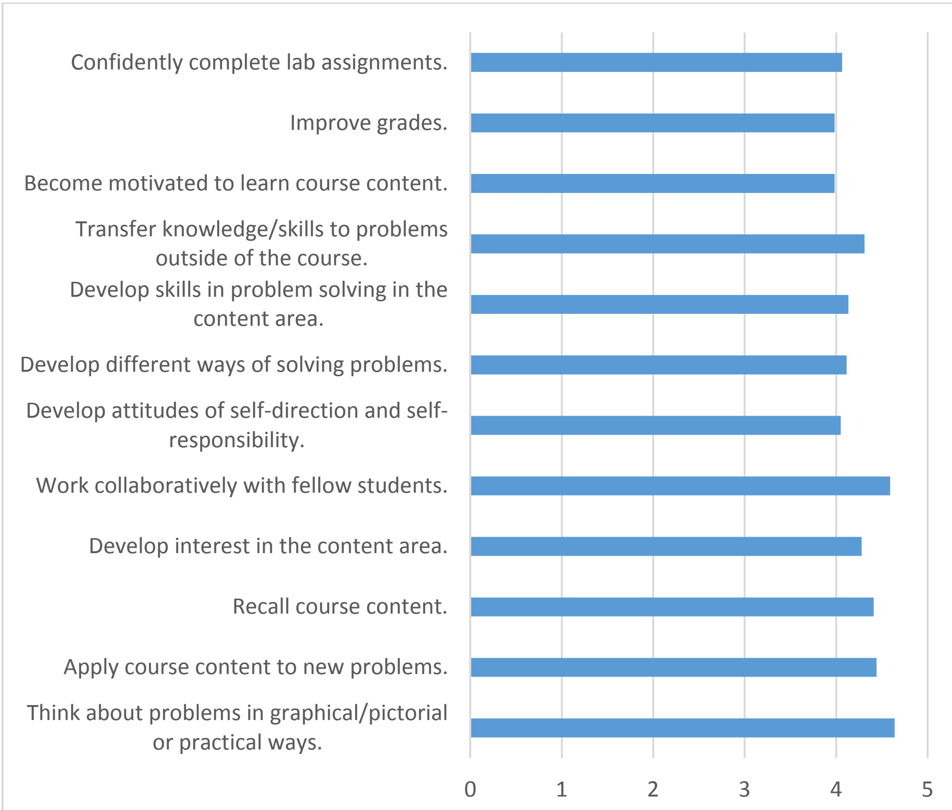

Figure 12: Spring post survey question indicating the students' ratings of the different benefits that the hands-on experiment had for them (N=61); where 5 is the highest rating for each topic. [10]

stationary and moving obstacles. The third week will involve placing the RC car on the treadmill. The final stage will give students a chance to test the limits of the RC car positional controller as the belt speed is varied and as the ramp angle is varied. Students will observe firsthand how the controlled car is able to handle external disturbances. They will also reconsider the adequacy of the PID controller to handle the situation where the car's wheels must still be turning while the positional error is driven to zero.

In summary, the VIP HOL team has been instrumental in the design and fabrication of a number of experimental platforms for use by other students. They have simultaneously been awarded course credit for their VIP project work and acted as *partners in education*. This paper highlights three categories of experiments that the VIP HOL team has completed: ones that can be used in a classroom to explore a basic concept within a lecture-based course, ones that can be used as do-it-yourself projects to teach skills in a campus makerspace environment, and ones that can be used as multi-week experiments in a laboratory course.

Acknowledgement

This research was supported by NSF grants TUES 1226065 and IUSE 1626362; Drs. E. Yaprak and A. Ilumoka are the respective contract officers. Finally, the authors give their sincere thanks to all student members of the Georgia Tech Vertically-Integrated-Program in Hands-On Learning (VIP-HOL), for their contributions to this effort.

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