Developing a Summer Bridge Course for Improving Retention in Engineering

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Abstract

This paper outlines the details of a summer bridge, project-based, cooperative, introduction to engineering pilot course developed and successfully implemented at Spelman College in an effort to increase the retention rate of students to be enrolled in its dual-degree engineering program. The course aims to expose incoming students of any STEM discipline to a broad array of practical and theoretical engineering principles for the purpose of helping students make informed decisions about pursuing engineering as a study major prior to the start of their freshman year. To satisfy this objective, the cross-disciplinary course that was developed is based on completing a software-driven, electro-mechanical engineering project that, at various times and to various extents, calls upon students to function in the capacity of an electrical engineer, a mechanical engineer, a technician, a mathematician, a computer scientist, a researcher and a communicator of technical material. In so doing, the students gain insight about how engineers combine knowledge from these diverse disciplines to solve a real problem—in this case, constructing and characterizing a 2-DOF, servoed laser system used to trace arbitrary patterns against a wall. Using an "inverted curriculum" approach that by-passes the first two years of the classic engineering curriculum, the course immerses the students directly into an engineering design project in an attempt to capture, as closely as possible, the end-goal of engineering training while providing a window to the challenges and gratifications of engineering both in practice and in an R&D setting. It was observed that, far from having the feared effect of driving the students to disinterest, challenging the students with a difficult curriculum of technical concepts to be used to solve a non-trivial but well-defined and tangible problem elicited high interest and thoughtful evaluations and re-evaluations of engineering as a study major. Details of the course, which involves building a circuit from a schematic, developing code for a multi-core microcontroller, learning and applying the concept of pulse-width-modulation to control servo motors and developing the required mathematical coordinate transformations to successfully control the orientation of the laser are discussed.

Introduction

In response to an increasingly consenting forecast of a shortage of engineers in the U.S. workforce over the next decade and the many associated ill-consequences \(^3, 14\), the President’s Council on Jobs and Competitiveness has set a national goal of graduating 10,000 additional engineers annually \(^15\). To meet this challenge, U.S. institutions need to increase and sustain engineering graduation rates by 13% over the 76,376 degrees conferred in 2011 \(^12\).

While there are potentially many pathways to achieving the target graduation rate, the President’s Council of Advisors on Science and Technology (PCAST) has identified retention of students who start out as engineering majors but fail to persist to graduation as one of the more effective and less costly avenues \(^14\). Indeed, research in the area of
persistence among engineering majors shows that on average only about 60% of students who start out as engineering majors eventually graduates with an engineering degree. Increasing the average persistence rate from 60% to 68% alone would surpass the target graduation rate set by the Jobs Council. The persistence problem is particularly acute among women and minority groups who not only collectively form an underrepresented majority, but also exhibit below average persistence rates. The persistence rate among women engineering students is estimated to be approximately 30%. For Hispanic students, the estimated rate is also 30% while African-American students exhibit an average persistence rate of 50%.

In a landmark study, Seymour and Hewitt address the causes and contributors to non-persistence and found that a strong predictor of students who persist and those who don’t to be the student’s declared reason for pursuing engineering as a study major. Students who pursue engineering careers because of interest in the discipline tend to persist while students who choose engineering for other reasons, including the all too often stated proclivity for mathematics, do not. Students in this second group clearly fail to understand that while being good at, and even enjoying, mathematics may be a prerequisite for engineering, it is not a predictor of compatibility with the discipline. This suggests a lack of understanding of what engineering is and what engineers do among these students. Indeed, studies suggest that students and the public at large have a poor understanding of what engineers do. Besides leaving students vulnerable to misguided stereotypes about engineering, this ill-informed state has at least a two-fold negative effect on recruitment and retention of engineering students entering college.

First, it creates the opportunity for false-starts on an engineering career that ultimately results in non-persistence even among students proficient in mathematics and the basic sciences. Second, it precludes engineering from consideration among students who, were they equipped with a more accurate image of engineering, might otherwise find the discipline appealing. Addressing the former effect potentially reduces the retention problem perhaps at the cost of reduced enrollment. Addressing the latter effect potentially offsets the loss by improving student recruitment into engineering.

**Hypothesis on an Effective Summer Bridge Engineering Module Course**

At Spelman College, students are offered many STEM degree options, including a dual-degree engineering program (DDEP) through partnerships with colleges and universities nationwide that offer engineering degrees. The summer bridge program is, in part, intended to first inform, then encourage selected STEM students to give engineering a second consideration with the ultimate objective of bolstering recruitment and retention of students in the DDEP. A central component of the program is an engineering module class that immerses students in a hands-on engineering project intended to inform the students about what engineering is by capturing, as closely as possible, the end-goal of engineering training while providing a window to the challenges and gratifications of engineering both in practice and in an R&D setting.
This paper covers the specifics of the engineering module portion of the summer program. In developing this course, the designers took the approach that the vast majority of incoming STEM students can be grouped into one of four categories.

First, there are DDEP students who have selected an engineering major out of interest in engineering. The historic tendency for these students to persist beyond the average suggests that these students have some level of understanding of what engineering is.

Second, there are DDEP students who have selected an engineering major for reasons other than genuine interest in the discipline (mathematical aptitude, parental urging, monetary motives, etc.). This group consists of declared engineering majors who, statistically, do not fully appreciate what engineering is all about and consequently are more likely to become non-persisters.

Third, there are non-engineering STEM students who have not considered engineering mostly out of lack of awareness of what engineering is and what engineers do.

Finally, there is a fourth group of non-engineering STEM students who have an understanding of what engineering is and have, nonetheless, opted to pursue a non-engineering STEM major.

These four broad groups can be further arranged into two broader classes of students. Students from the first and fourth group we classify as informed decision makers as far as major selection is concerned. These students tend to persist in their choice to select or not select engineering as a study major and are not the target of the summer bridge course. Students from the second and third groups constitute what we will call the uninformed class and would ideally be the type of students targeted by the course.

The difficulty of accurately identifying which class each student falls in coupled with historic experiences on the relative size of each class led to the decision of assuming that, for purposes of designing the course, all incoming students fall into the uninformed class.

Our central hypothesis in developing the summer bridge course is that improving the retention rate of engineering students, requires improving the selection process for students who enter the engineering program. This means that we must not only identify incoming students with declared engineering majors who may not be a good match for engineering, but we must also identify students who are potentially good matches, but who, for any number of reasons, have not considered a career in engineering. We further suggest that empowering self-identification through a hands-on exposure to engineering is an effective method to achieve this.

Because the summer bridge program takes place during the summer preceding a student’s freshman year, it presents a good opportunity to migrate incoming students from the uninformed class to the informed class prior to the first official day of the student’s college career. The ideal outcome of this effort is to offer an early egress opportunity to likely non-
persisters while offsetting the loss with an ingress opportunity to potential persisters not currently in the DDEP. Ultimately, a successful program should result in an overall improvement in both the persistence rate and graduation rate even if starting at the disadvantage of a reduced number of students entering the DDEP.

Naturally, there is some risk and some apprehension in developing a course that has a stated objective of offering an egress path from the very discipline it aims to advocate. This is particularly sensitive in engineering where, real or imagined, there exists the image of a curriculum designed to “weed out” weaker students. To address this, the designers of the course were careful to specify a course with a format that is supportive, encouraging and that invites questions and open discussions 9. Egress should be the result of an informed decision, not intimidation by the curriculum.

**Pedagogy of the Summer Bridge Course**

In order to test the stated hypotheses, the designers used the 2012 Summer Bridge Engineering Module Course as a pilot course. To achieve the desired goal, the designers called for coursework that is project-based and fulfills a number of requirements. These are outlined below.

*Cross-Disciplinary*

Engineering is a broad field comprised of many sub-disciplines including chemical engineering, electrical engineering, mechanical engineering, civil engineering and many other sub-specialties. Additionally, the practice of engineering calls upon many other disciplines including computer science, mathematics, physics, optics and numerous others. While no single project can capture aspects of all these inter-related disciplines, the course project should aim to capture components of as many of these fields as possible.

*Vertical Diversity*

Engineering is also practiced at many levels, from the technician to the researcher. The course project should aim to engage student at multiple levels, including the technician level, the design level, the development level and the research level.

*Foster Collaborative Learning*

The project needs to be a cooperative effort of student groups. Research shows that collaborative learning is not only an effective pedagogical instrument 17, it is also deemed to be an important part of engineering training both from an industry 13 and accreditation point of view 1.

*Hands-On, Non-Trivial*

The project must be hands-on, non-trivial and relevant to common experiences. To achieve this, the engineering curriculum is “inverted”: the project is more akin to what a senior engineering project might look like rather than the mathematical and basic science foundations offered by the first 2 years of the classic engineering curriculum. Again, care
must be taken here to develop a class that is an accurate representation of engineering in terms of principles, its rewards and the level of effort required to succeed academically and in practice. Whereas “weed out” classes carry the connotation of thinning the student population by attrition, the objective here is to allow students to self-select into and out of the DDEP based on an experience that accurately portrays the engineering discipline.

Zero Pre-requisites
Beyond what can be expected of a typical high school graduate, the project must have no engineering or technical pre-requisites. At the same time, the project needs to be sufficiently advanced that it defies completion without acquiring a few non-trivial, technical concepts. Use of standard engineering tools (oscilloscopes, MathCAD, spectrometers, CAD systems, spectrum analyzers, etc.,) that require a significant investment of time to master have to be kept to a minimum given the 6-week duration of the course.

Servoed Laser Project
Students in the 2012 Summer Bridge Program were offered a choice of two engineering modules. The first emphasized the thermal, mechanical and chemical aspects of engineering while the other focused on the integration of electric, electronic and computer systems to control a mechanical device. A detailed description of this latter course, which is based on using a microcontroller (MCU) to drive a pair of servo motors that carry a laser pointer, is covered here.

Figure 1 is a depiction of the mechanical assembly. In the picture, a laser diode is seen to be mounted on the horn of a hobby servo motor (called the Zenith or “Y” servo) that orients the pointer up or down. The Y motor is mounted on the horn of a second motor (called the Azimuth or “X” servo) that pivots the entire mechanism left or right. Thus, properly controlled, the servo pair can point the laser diode in an arbitrary direction. Control of the servos is achieved by programming a microcontroller (not shown).

The broad tasks to completing the project include:

- Mechanical assembly
- Wiring the circuit
- Programming the MCU
- Controlling the motors
- Generate shapes

Figure 1: Exploded view of the mechanical assembly of a servo motor pair that arbitrarily points a laser diode.
• Hypothesize and correct for distortions in the shape
• Write a technical paper and deliver a technical presentation of findings

These are detailed below.

• **Mechanical Assembly**
The mechanical assembly task proved to be an effective means of immediately engaging the students in the project. In particular, harvesting the laser diode from a common laser pointer and re-purposing it for the project offered a “tear-down” and re-engineering opportunity that elicited many questions about how the device functioned and how the laser pointer itself is manufactured. Further, de-soldering unwanted components (the laser pointers used were multi-function devices which included a miniature flashlight and a dark light which were not needed) and soldering leads to the diode after it had been removed from the pointer turned out to be a new experience for most of the students. Subsequently powering on the laser with an external power source lead to immediate satisfaction for having successfully soldered the leads onto the device then operated it in a new manner.

• **Wiring the Circuit**
Most of students in the program were new to electronic circuits assembly and most had never worked with an electronic schematic. Breadboarding the required circuit from a schematic diagram presented another opportunity to experience technical materials absent of equations and theory. As an introductory measure, the “assisted schematic” of Figure 2 was developed and supplied to the students. The figure can be seen to be a pictorially augmented (vs. fully symbolic) schematic diagram of the MCU and supporting peripheral circuit used to drive the laser diode and the servo motors.

![Figure 2](image-url)
Programming the MCU

Of the 9 students enrolled in the pilot program, only one had programming experience of any kind. Thus, fully half of the six-week long course is dedicated to learning the basic concepts and mechanism of programming the MCU. Proper selection of the MCU and programming language plays a key role in enabling students with no prior experience to develop working code in the allotted time. For this purpose, the MCU used is the 8-core Propeller P8X32A-D40 made by Parallax, Inc. This MCU and the associated SPIN programming language used to program it are developed by Parallax specifically for academic purposes. Thus, the language and the programming interface are clean, simplified, and relatively easy to learn. In a short period of time, students are able to write programs that toggle the various I/O pins on the device and use this to strobe the laser and perform other simple tasks. The immediate physical manifestation of the code they develop was found to encourage many questions about what else MCUs can do and served to motivate interest in further programming the device.

- **Controlling the Motors**

The two tasks that proved to be of greatest technical difficulty for the students both have to do with controlling the motors. First, the students are introduced to the concept of pulse width modulation (PWM) which is the signaling convention used to control the position of the servo axes. This, the students grasped without much trouble. Then, the students wrote a simple program to generate the PWM pulse train. Again, this they accomplished without much difficulty. The challenge came when they attempted to assemble all these concepts. Specifically, they had trouble correlating a timing specification which controls the width of the output pulses specified in units of MCU clock cycles in their program to the desired motor position. This showed that, while the students seemed to have mastered all the underlying concepts and steps to drive the motor, vertically integrating what they had learned to achieve a goal proved to be the greater challenge.

Second, because the two motors need to be operated simultaneously, students are introduced to the concept of parallel programming on a multi-core processor. Specifically, the students write a 3-threaded application that runs on 3 of the MCU’s 8 cores. One core generates the PWM signal for the X servo. Another core generates the PWM signal for the Y servo. The third core coordinates the movement between the two PWM cores. Difficulty with this concept was expected and observed. A successful grasp of the concept came only after the students were challenged to drive both motors with a simple single-core program. Once the difficulty and limitations of that approach became apparent, the need and advantages of the multi-core approach became clear and the students were able to progress.

- **Generating Shapes**

Once control of the two motors is established, the students begin the process of using the device to trace out patterns. Successfully doing this for even the simplest shapes requires the establishment of a coordinate system and performing some mathematics. For example, to trace out a pentagon, the students use graph paper to calculate the relative X-Y coordinates of the vertices with respect to the center of the pentagon. Then, they translate
these mathematical X-Y coordinates through what amounts to an empirically derived coordinate transformation (from X-Y to pulse width) to trace out the pattern. A few long-exposure images of final patterns generated by the students appear in Figure 3.

**Figure 3:** Long-exposure photographs of a few patterns traced out by the servoed lasers. In each case, exposure times are on the order of 0.5-3 seconds.

- **Hypothesize and correct for distortions in the shape**

All students were required to generate a square as shown in the first image in Figure 3. Figure 4 shows the typical progression of generating a more complicated shape. During these exercises, students soon realize that simply getting the coordinate mathematics right is inadequate to engineering a good solution. They are asked to hypothesize about what gives rise to the distortions (like the overshoot in the case of the square) they observe and to think about ways to correct them. During this “research” phase, the students conducted experiments by modifying their code to generate larger or smaller patterns while driving the servos at faster or slower speeds to study the effects on shape distortion. The students also experimented with adding additional weights to the servo’s payload. All students correctly identified inertia as a major contributor to distortion though time constraints permitted only some students to devise and implement solutions.

**Figure 4:** Typical progression of generating a target shape. In forming this image of a handbag, this student group is seen to struggle first with the coordinate transformations, then with the ill-effects of the real-world system.
• **Technical paper and technical presentation**

The students formalized their findings in a proper technical paper complete with abstract, introduction, procedures, analysis and conclusion. This they did by following a supplied model paper. The contents of the paper is then summarized into a technical presentation delivered before members of the faculty, peers, upperclassmen and industry professionals. This too, the students did with the aid of a supplied model presentation. Research supports the communication of technical matter as an essential component of engineering training.\(^{13}\)

**Analysis on the Effectiveness of the Course**

The pilot program was comprised of nine STEM students, whom we will label as students “A”, “B”, “C”, etc. The students were randomly paired at the start of class. Student “I”, who showed an immediate technical aptitude, was paired with the instructor. At the beginning of the course, the students were informally, orally surveyed through private communications with the instructor and were asked about their interest in and understanding of engineering. While students were selected for the program based on a stated interest in engineering, this opening survey made it clear that other motives for entering the program (resume building, stipend, parental urging, etc.) may have been equally influential. Based on their responses, the students were subjectively estimated to be either “informed” or “uninformed” and were grouped under one of the “interest level” columns shown in Table 1. The students were similarly surveyed at the end of the course.

<table>
<thead>
<tr>
<th>Student Class</th>
<th>Students Expressing Serious Interest in Selecting An Engineering Major</th>
<th>Students Expressing Moderate Interest in Selecting An Engineering Major</th>
<th>Students Expressing No Real Interest in Selecting An Engineering Major</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start of Engineering Module Course</td>
<td>Informed</td>
<td>Uninformed</td>
<td>Informed</td>
</tr>
<tr>
<td>End of Engineering Module Course</td>
<td>A, C</td>
<td>---</td>
<td>I, B, F</td>
</tr>
</tbody>
</table>

*Table 1:* Assessment of student interest and understanding of engineering prior to and after completing the course.

Most of the incoming students (all but student “B”) were classified as “uninformed” about engineering. This classification is a subjective assessment by the instructor based on a student’s ability to approximately articulate the basic idea that engineers use math and science to solve real problems. By the end of the course, the students have gone through the process of applying technical and mathematical concepts to engineer an operating device, and are all considered “informed” by experience.
While statistically, what can be garnered from this pilot study is limited by the set size, much can be learned by examining the data in Table 1. First, the fear of driving students away from engineering by challenging them to solve a difficult problem appears to have been largely unfounded. Neither the difficulty of the technical material nor the inevitable frustrations of applying them to a real problem served to “turn off” the students in any measurable way. In fact, comparison of interest levels before and after the course indicates a net gain of potential incoming DDEP students.

Second, the migration pattern of students across the three interest columns provides an additional source of information. In Table 2, we identify students who move from a column of lower interest to a column of higher interest as positive migrators. Conversely, students who move from a column of higher interest to a column of lower interest, we identify as negative migrators. Students who migrate to adjacent columns are called single level migrators. Any student who’s level of interest shifts beyond an adjacent column is a double-level migrator. Such a student would have exhibited a dramatic change in her stance, positive or negative, on engineering.

<table>
<thead>
<tr>
<th>Student</th>
<th>Single Level Migration</th>
<th>Double Level Migration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informed student</td>
<td>A, C, F, I</td>
<td>None</td>
</tr>
<tr>
<td>Uninformed student</td>
<td>None</td>
<td>I</td>
</tr>
<tr>
<td>Informed student</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Uninformed student</td>
<td>None</td>
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<tr>
<td>Informed student</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Uninformed student</td>
<td>None</td>
<td>None</td>
</tr>
</tbody>
</table>

Table 2: Migration of student interest as a result of the engineering course.

From the tables, it can be seen that four of the nine students in the pilot course migrated their interest level. Three of these (students “A”, “C”, and “F”) are positive migrators and one, student “I” is a negative migrator.

No informed student (of which there was only one) experienced a migration of interest and no student experienced a double-migration.

Anecdotally, the tabulated data supports the premise of our hypothesis on identifying students who are good fits for engineering in several ways. First, we predicted that informed students are unlikely migrators and are therefore likely persisters. In the current study, the single informed student had insights about engineering through family ties. Her decision not to pursue an engineering degree was established with a clear understanding of what engineering entails. As could have been predicted, she was
unswayed by the course. Next, we confirmed that there are uninformed students entering the DDEP who, had they been informed, would probably not select engineering as a major. Concurrently, there are uninformed students not entering the DDEP who, were they informed, would seriously consider engineering as a major. This first group is represented by student “I” who, through the process of moving from the “uninformed” to the “informed” class, migrated negatively from “serious interest” to “moderate interest”. The second group is represented by students “A”, “C” and “F” who, through a similar process of migrating from the “uninformed” to the “informed” class, migrated positively in their interest level. Validation of the proposed hypothetical prediction that students like “A” and “C” will exhibit greater persistence than students like “I” will require a follow-on study with a greater pool of control subjects and several years of data tracking.

Conclusion

This paper discusses a hands-on, project-based summer-bridge engineering course that tests the hypothesis that informing students about choosing engineering as a study major prior to the first day of their college studies leads to an incoming class of students that will exhibit higher persistence and higher graduation rates than a similarly uninformed class. It is hypothesized that non-persistence in engineering is significantly caused by the selection of engineering for reasons other than interest in the discipline. It is further hypothesized that these errors of selection is largely the result of uninformed or misguided notions about engineering. An assessment of the pilot bridge program, which aims to inform STEM students about engineering, fails to reject either hypothesis and suggests the need for a larger, long-term follow-on study. The course is shown to have succeeded in empowering students to make informed decisions about engineering. The suggested follow-on study is needed to verify that, indeed, this informed decision making does improve both retention and graduation rates.

References


