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Porting a University Introduction to Design Course to a Semester Long High School Course Based on Open-Source Hardware and Arduino - Evaluation

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Brian Huang is an Education Engineer for SparkFun Electronics, a cutting edge open-source hardware and electronics education company. Brian started his career in engineering with wireless transport technologies for ADC Telecommunications in Minneapolis, MN. While working at ADC, Brian volunteered at the Science Museum of Minnesota and quickly discovered a passion for teaching and working with students - especially in an environment that fostered and supported the ”wow” factor associated with inquiry and discovery. In 2007, Brian left the world of engineering to pursue a career in education. For the past 5 years, Brian has taught various levels of high school physics, mathematics, applied technology, and robotics.

Brian joined Sparkfun Electronics to help integrate ”tinkering,” electronics, and computational thinking into the classroom. One of his goals is to help teachers to de-mystify how household consumer electronics work. With a few simple tools, classrooms can excite and encourage students to explore the possibilities of microcontrollers, electronics, and physical computing.

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Introduction

For over twenty years, a first year introduction to engineering design course at the University of Colorado Boulder has provided an experiential hands-on design experience that has been shown to significantly improve retention of engineering students [1]. Many studies have previously described K-12 STEM programs (as reviewed in [2]) however this curriculum attempts to take advantage of the strengths of the engineering design course at the University of Colorado Boulder and Sparkfun Electronics hardware. This course introduces a variety of engineering disciplines including mechanical, electrical, and computer engineering using both formal delivery of technical curriculum and hands-on design projects. We leveraged the existing curriculum—that boasts these impressive retention results—to develop a high school level introduction to design course using products from SparkFun Electronics.

Methodology

We made several adaptations and adjustments to the original course with the understanding that students in high school engineering or pre-engineering programs may have a different level experience from those enrolled at a top-tier university. In addition, we understand that many high schools do not have access to the same materials, tools, and resources that most university programs do. Taking these facts into consideration, we adjusted and modified the course to fit into an average high school classroom. The course was arranged so that it can be taught in a classroom with only power outlets and community/personal computers.

The course materials were adjusted for both student and teacher alike. The handouts provided to the students were adjusted to include more structure and detail. For example, the soldering workshop using the Simon Tilts product from SparkFun was revised to include more instruction and definitions concerning the various components that are included in the kit. Early in the workshop, resistors are soldered into a through-hole printed circuit board. In the revised high school curriculum, the workshop describes the purpose of a resistor and prompts the student to answer questions concerning the resistor used at this step. The collegiate version simply assumes prior knowledge concerning basic electrical components and does not intervene during the assembly process. Another practical example of an adjustment made occurs in the lecture concerning computer programming. The various computer programming concepts including variables, functions, and structures are presented as an analogy to parts of speech like nouns, verbs, and punctuation. The analogy grounds the computer programming concepts into a discipline (language arts) that high school students have more familiarity. The instructor materials were also revised to provide more background information concerning the lessons and more detailed lesson plans. A daily lesson plan was developed for the high school version including a minute-to-minute timeline of the day. A significant difference in a high school course is a focus on formative assessment, progress monitoring, and student maturity. For example, daily openers and closing reflections are included in our course revision that are not typical in a college course. Recommendations are provided in the lesson plans to guide high school teachers on how best to coach the student design teams and organize the hands-on materials/exercises. The rationale for these changes is the need for the material to be easily digestible by high school students and teachers who have not been involved in a hands-on design course previously.

The hardware items used in the curriculum did not change between the collegiate and high school versions. Both curricula use the SparkFun Inventor's Kit (SIK), the Simon Tilts soldering kit, and a set of hand-tools. In both cases, the classroom simply requires power outlets and community/personal computers. The only difference between the two implementations, as it relates to hardware, was the number students per team (and kit). It was suggested that the high school curriculum organize the class into student teams of 2-3 whereas the collegiate student teams consist of 5-6 students. The rationale concerning this difference is due to the maturity of the students and the ability of student teams to work effectively on open-ended, long-term design projects. High school students typically require more structure and accountability compared to their collegiate counterparts and therefore should be organized into smaller groups. The smaller teams ensure that each student will have more experience using each piece of hardware and hopefully promote self-efficacy and self-directed learning for high school students.

The software involved in the course was revised to use open-source programs. Students will be using the Arduino programming environment to interface with the SparkFun products. This software package has been, and will always be, an open source format with extensive libraries and example code provided. The computer aided design software used in the existing collegiate course was a proprietary software package called Solidworks (Dassault Systems, Inc.) but was revised for the new curricular implementations to an open source CAD software package called SketchUp (Trimble Navigation Limited). While Solidworks is a powerful CAD tool, the students are not required to utilize all of the functionality of Solidworks (like finite element analysis, animation simulators, etc.) in this course. Therefore, the SketchUp open source program provides enough functionality for students to model prototypes and assemble components in CAD before proceeding with hardware prototypes. Also, the open source software does not add extra financial burden whereas the proprietary software would require thousands of dollars to purchase.

We made changes to the collegiate curriculum to ensure that the high school version would be widely-accessible across a wide variety of high school environments. The course materials were reworked to ensure that novice or experienced teachers could implement this curriculum. The hardware was originally designed so that the classroom simply requires power outlets and community/personal computers. The software was revised to require only open source programs that will always be available for no cost. We hope these revisions allow for this curriculum to be implemented in many, many high school classrooms in the future.

Implementation

During the spring 2015 semester, we are piloting this program in Centarus High School in Louisville, Colorado with four sections of Introduction to Engineering class and two sections of Introduction to Computer Science class. A total of 155 students will experience this curriculum. The high school is currently using Project Lead The Way (PLTW) as their primary curriculum for pre-engineering. In this case, two teachers are using our curriculum instead of the PLTW materials used in the past. Both teachers will be interviewed throughout the semester to gather feedback on the curriculum. Also, classroom observations will occur throughout the semester and a group interview will take place at the end of the semester to gather quantitative and qualitative feedback from the students.

Our aim is to compare and assess the advantages, and student growth, associated with using our curriculum as well as identify changes in attitude, retention, college outlook, and engineering identity. A pre- and post-survey were created to assess whether students indicate a change in engineering identity as measured by centrality, why they are studying pre-engineering, intent to persist to college in a STEM field, self-identified skills that may be part of the course learning objectives, and attitudes toward creativity, failure, ambiguity and the design process. Student knowledge of twelve, course-related definitions was also included to see if definition-based content gains can be measured. The pre-survey also asked questions about student demographics and assessed their level of grit. These measures are also available for the original collegiate course so comparisons can be made.

At this point in time, the pre-survey was administered and is discussed below. The post-survey will be administered later in the spring semester and results will be included at the conference.

Results

During a pre-survey administration, 155 high school students responded, of which 117 were enrolled in a freshmen Introduction to Engineering course and 38 were enrolled in a higher level Computer Science (CS) course.

- The students include 24% female, 13% English language learners and 10% potential first-generation college-bound students.
- When asked if they intended to attend college and major in a STEM field, 69% responded that they “probably” or “definitely” would.
- They were given 12 matching definitions related to the course content. Examples of definitions include 1) circuit - a closed loop that provides a conductive path between a power source and load, 2) code - a specific and concise set of instructions that are interpreted and performed by a microprocessor/computer. The average pre-survey definition matching score was 51% for the Intro class and 84% for the CS course indicating a base knowledge level greater than that expected by guessing alone (pure guessing would produce between 9-26% depending on whether students considered these as independent or dependent). The two terms most often defined correctly were “teamwork” and “circuit” while those most often incorrect were “variable” and “digital signal.”
- In a self-assessment of their course related skills, students rated their preparation to incorporate the “iterative design process” lower than all other listed skills. Students rated their preparation to incorporate “creativity”, “teamwork” and “problem solving” as relatively high.

The post survey will ask students to reply to the same prompts concerning the course related skills and vocabulary. These results will be collected and analyzed in time for the ASEE 2015 conference in June.

Conclusion

The porting of a university introduction to engineering design course to a semester-long high school course based on open-source hardware and Arduino was implemented and evaluated. The course provide curriculum on a variety of inter-related engineering disciplines like mechanical, electrical, and computer engineering. The course was based on a collegiate level course at the University of Colorado Boulder that was shown to significantly improve the retention of engineering students. The hope is that this pilot program will provide evidence of similar benefits and that future implementations will help validate the efficacy of the curriculum. In the future, the goal is that this curriculum could even provide college credit for high school and colleges that are in collaboration. The curriculum and hardware will be available to the greater public through SparkFun Electronics, Inc. Then, educators from across the globe will have a powerful tool to teach and attract students to the field of engineering.

[1] N. L. Fortenberry, J. F. Sullivan, P. N. Jordan, and D. W. Knight, "Engineering education research aids instruction," *Sci.-N. Y. THEN Wash.-*, vol. 317, no. 5842, p. 1175, 2007.
[2] *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*, Pap/Cdr edition. Washington, D.C: National Academies Press, 2009.