Increasing Student Confidence in Conducting Independent Experiments using Arduino Technology

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Abstract

At the University of Tennessee at Chattanooga (UTC), all mechanical engineering students are required to take a senior level Experimentation Laboratory which requires them to put into practice much of the knowledge they gained during their undergraduate careers. Four of the eight required labs cover multiple areas of solid mechanics while the remaining four labs focus on the thermal fluid sciences. Until recently the last six weeks of the course consisted of student teams working on small projects aimed at improving experiments conducted in the various engineering labs. As is often the case with group work, the level of competence gained from completing these projects varied greatly among the members of each team. Thus, it was decided by the faculty teaching the course, to increase opportunities of student learning by requiring completion of small projects by individual students rather than student teams. After examining the applications and cost of several Arduino Kits, it was determined that these are excellent for conducting simple, relatively short experiments easily completed by individual students. The desired outcomes for revising the laboratory to include the individual projects are: 1) to increase student ability to conduct experiments outside of the classroom using new technology, and 2) to increase student confidence in conducting an independent project. The information and findings provided in this paper are based on the Experimentation Laboratory of Spring 2021. Both a pre- and post-survey were completed by the students to evaluate the effectiveness of the course revision.

Keywords

Experiential Learning, Arduino Technology, Student Confidence, Effective Laboratory Learning

Introduction

All mechanical engineering students at the University of Tennessee at Chattanooga (UTC) are required to complete a two-hour senior level laboratory aimed at revisiting many of the major topics they encountered throughout the curriculum. The class meets on Mondays for fifty minutes to introduce the topic for the week, and then for a three-hour lab experience on either Wednesday or Friday. For the first eight weeks, teams consisting of three to five students' alternate labs focused in either the Mechanics or Thermal Fluids area. For the Mechanics side of the lab, topics covered in classes such as Machine Design and Mechanics of Materials are demonstrated, while for the Thermal Fluids portion topics covered in classes such as Thermodynamics, Fluid Mechanics and Heat Transfer are presented. A secondary goal of these experiments is to introduce students to different types of sensors that can collect the necessary data to complete the calculations conducted during their typical lecture classes.

In previous iterations of this class, the last six weeks consisted of a team project focused on improving experiments in several of the labs taken by mechanical engineering students. Many of these projects consisted of introducing new sensors to existing equipment thus providing students with an opportunity to apply many of the techniques covered in the eight previous labs. While many of these projects provided excellent learning opportunities, over time it was observed that two issues frequently occurred. The first issue is that six weeks rarely provided enough time to complete an entire project. Thus, most projects were completed by multiple teams over several semesters, so that students rarely had an opportunity to see an entire project from start to finish. This also limited the technical competence that could be gained from the actual implementation of a design solution. The second issue is an imbalance in workload among team members. In completing the eight labs team members would rotate roles so that every student had an opportunity to experience different elements of the lab multiple times. However, with the final project it was discovered that certain team members were heavily involved in working directly with the systems while other team members were responsible for indirect roles such as composing reports. It was observed that students who were typically confident in their hands-on skills tended to "take-over," limiting contribution of those not as assured of their abilities. With these issues in mind, it was determined a change that (1) allows students to complete a project and (2) insures everyone is directly involved with the project would be beneficial. It should be noted that while many studies have proven the effectiveness of working within teams, there have also been evidence that at times it can reduce the amount of individual learning that takes place.[1,2]

To accomplish these goals, it was decided that an individual project would be completed by each student. The project would be based on one of the previous labs completed during the semester to relate what they had learned to a more "real-world" problem. To determine the effectiveness of this project, the faculty decided to perform a pre and post survey of the class. The goal of the survey was to determine: 1) how student confidence in learning new technology changed throughout the project, thus enabling them to complete a project outside of the classroom and 2) how student confidence to conduct an independent hands-on "real-world" lab changed throughout the project.

It was hypothesized that students will increase both their confidence in working with the Arduino and supporting software technologies and their confidence in conducting individual projects outside of an academic environment.

Background

Arduino technology was chosen over other platforms, such as Raspberry Pi, for several reasons. First, one of the instructors teaching the class had become familiar with the platform while completing consulting work on an air quality sensor. During this time the instructor discovered that the technology was reasonably intuitive and very inexpensive. This platform has also been proven effective across various engineering disciplines and age groups.[3-7] Finally the technology had also been previously implemented in a graduate level mechanical engineering class at UTC, albeit with more focus on controls than sensors.

Arduino Supported Project

During the final two weeks of the eight-laboratory sequence, students complete an analysis of a typical heat pump trainer. This includes conducting a first law analysis of the four components (compressor, condenser, evaporator, and expansion valve) as well as a psychometric analysis of the air/water vapor mixture crossing the condenser and evaporator. This is one of the few times students get a chance to complete a full cycle analysis of a thermodynamic system.

To reinforce and expand the students understanding of these systems the final project selected by the faculty focused on introducing students to determining a load on a heat pump. This would help students understand how to size a specific heat pump such as the one they had previously analyzed. While measuring the overall load of a house or apartment is difficult with the instrumentation selected, the load produced by a single room is not; thus, a single room was chosen for measurement. Specifically, students were tasked with determining how much additional load a shower, run for five and ten minutes, would place on a typical system due to the heating of the air within the bathroom. They were additionally required to determine a typical Coefficient of Performance of a heat pump system to estimate the cost required per month.

The Sunfounder Ultimate Sensor Kit V2.0 for Arduino was selected for collecting the necessary data to complete the project. Forty of these kits were purchased along with an Arduino Uno board (approximately $50 for each kit and board), and distributed to each student in the class at the beginning of the project. These kits contain all wiring needed to connect each sensor to the board, without soldering, as well as a USB cable to provide power to the board and sensors and to transfer data to the computer. All students were required to download the open source Arduino Integrated Development Environment (IDE) software for programming the board, and the Processing software (also open source) for receiving data from the board and distributing it to appropriate files for analysis.

The first three weeks of the project were used to introduce the new technology to the students. The kits provide excellent tutorials on how to connect the sensors to the board, as well as software that can be uploaded and used to take data. On Monday of the first week the kits were distributed and a brief presentation was given discussing Arduino hardware basics. For the labs conducted on Wednesday and Friday students were initially guided by the instructor on how to hook up a single sensor, load the software necessary to read the sensor onto the Arduino board, and examine the data being measured. Students were then allowed to “play” with the other sensors to become more comfortable with the hardware.

On Monday of the second week, students were given a lecture regarding Arduino Software basics. For the Wednesday and Friday labs the students were instructed on how to connect the three sensors they need to complete the project, namely the thermistor, humiture and barometric pressure sensors. They also developed the code necessary to read and output the data to the computer. For the third week the students were introduced to Processing software in the Monday section, and then during the Wednesday and Friday sections they implemented the code to capture data on their computers and send it to files for analyzing in Excel. During the fourth week the students were allowed to conduct their studies at home and were not required to attend class unless they had questions or difficulties with the sensors. The fifth week students composed their final report for the class and the last week was used as a review.

Much of the final report consisted of detailing the data taken, how the data was used to calculate the energy absorbed by the room, and the cost that was associated with this energy based on local utility rates. The first law calculations enhanced both the work completed in the previous heat pump lab, as well as material covered in both Thermodynamics classes taken at UTC.

Survey Description

Before the start of the project students were provided a pre-survey (shown in Figure 1.0) to determine how much experience they had with the three pieces of technology used, their perceived ability to learn the software and hardware, and their perceived ability to conduct an independent “real world” experiment. A five-point Likert Scale was used.

ENME-4470 Project Pre-Survey

Please rate your level of experience on a scale of 1-5 with 5 being the most experienced. Circle your answer.

1. Ability to work with Arduino hardware. 1 2 3 4 5
2. Ability to work with Arduino Software. 1 2 3 4 5
3. Ability to work with Processing software. 1 2 3 4 5

Please rate your level of confidence on a scale of 1-5 with 5 being the most confident. Circle your answer.

4. Ability to learn Arduino hardware. 1 2 3 4 5
5. Ability to learn Arduino Software. 1 2 3 4 5
6. Ability to learn processing software. 1 2 3 4 5
7. Ability to complete a hands-on project independently. 1 2 3 4 5
8. Ability to translate lab lessons to “real-world” applications. 1 2 3 4 5

Figure 1.0: Pre-Survey

Once all projects were completed, the students were provided a post-survey (shown in Figure 2.0) to determine their confidence in using the hardware and software, and their perceived ability to conduct an independent “real-world” project. A five-point Likert Scale was used.

ENME-4470 Project Post-Survey

Please rate your level of confidence on a scale of 1-5 with 5 being the most confident. Circle your answer.

1. Ability to use Arduino hardware. 1 2 3 4 5
2. Ability to use Arduino software. 1 2 3 4 5
3. Ability to use processing software. 1 2 3 4 5
4. Ability to complete a hands-on project independently. 1 2 3 4 5
5. Ability to translate lab lessons to “real-world” applications. 1 2 3 4 5

Figure 2.0: Post-Survey

Results

Thirty-five students completed the pair of surveys. Nineteen of those students are considered transfer students – completing most of their math and /or science courses at another institution such as a community college. Table 1 provides a summary of the descriptive statistics from the surveys. The post survey results are shaded.

Table1: Results Descriptive Statistics

Variable	Total Count	Mean	SE Mean	StDev	Minimum	Q1	Median	Q3	Maximum
Pre Q1	35	1.657	0.188	1.110	1	1	1	2	5
Pre Q2	35	1.400	0.143	0.847	1	1	1	2	5
Pre Q3	35	1.743	0.150	0.886	1	1	1	2	4
Pre Q4	35	4.314	0.158	0.932	2	3	5	5	5
Pre Q5	35	4.057	0.136	0.802	3	3	4	5	5
Pre Q6	35	4.057	0.147	0.873	2	3	4	5	5
Pre Q7	35	4.371	0.136	0.808	3	4	5	5	5
Pre Q8	35	4.286	0.139	0.825	3	4	5	5	5
Post Q1	35	4.629	0.093	0.547	3	4	5	5	5
Post Q2	35	3.943	0.142	0.838	2	3	4	5	5
Post Q3	35	3.743	0.144	0.852	2	3	4	4	5
Post Q4	35	4.686	0.080	0.471	4	4	5	5	5
Post Q5	35	4.543	0.103	0.611	3	4	5	5	5

The major GPA of each student was also identified. The mean GPA of the 35-member sample is 3.113 and its standard deviation is 0.475. The distribution of the GPAs is shown in Figure 3.0. Figure 4.0 illustrates, using the Anderson-Darling (AD) Normality test, that the GPA sample follows a normally distributed population. (The plot of points is relatively straight. The AD value equals 0.243 which is relatively small. The p-value for the test is 0.75. Thus, the hypothesis that the data follows a normal distribution cannot be rejected.)

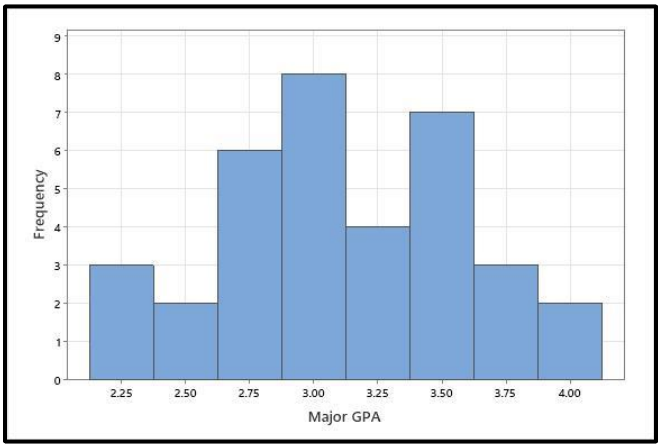

Figure 3.0: Distribution of Major GPA of Students

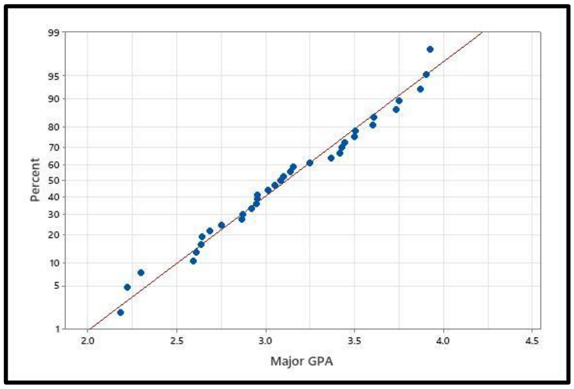

Figure 4.0: Normality Test of Major GPA

The spread of the GPAs with respect to transfer student status was also identified and are illustrated in the boxplots shown in Figure 5.0 and the histograms shown in Figure 6.0. In Figure 6.0 the hatched lines indicate the distribution of transfer student grades.

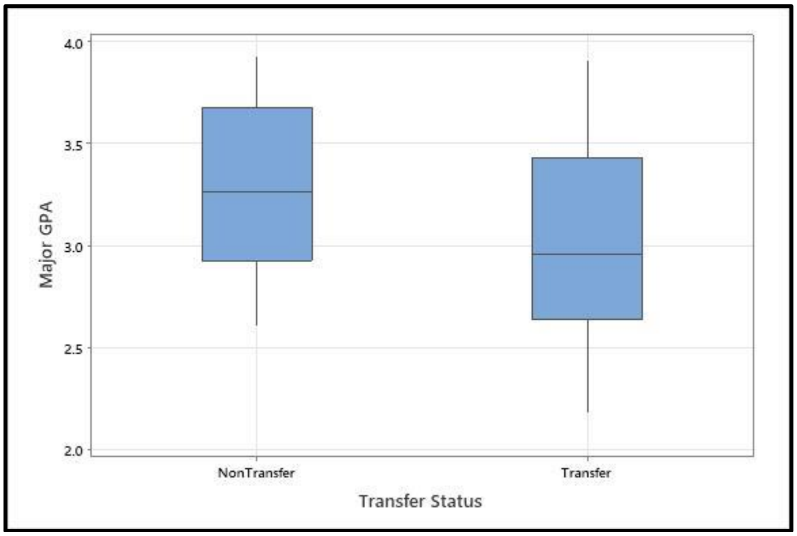

Figure 5.0: GPA Non-Transfer vs Transfer Student

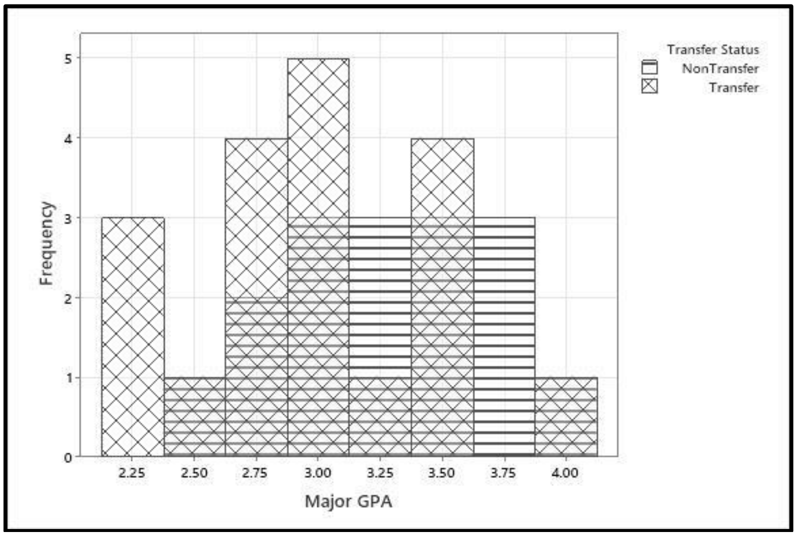

Figure 6.0: Histogram of Major GPA

Findings

The findings address two hypotheses associated with student participation in the course project:

- Students will increase their confidence in working with the Arduino hardware and supporting software technologies
- Students will increase their confidence in single-handedly conducting “real-world” projects outside of an academic environment

Hypothesis 1: Confidence in Working with Technology

The pre-survey (questions 1, 2 and 3) indicates students do not have much experience with working with Arduino hardware (question 1) or with using Arduino software or processing software (questions 2 and 3) at the start of the course. The blue unhatched boxplots in Figure 7.0 illustrate the low experience level. The blue plots also indicate there are a few students with experience with the Arduino technology - these students, however, are considered outliers.

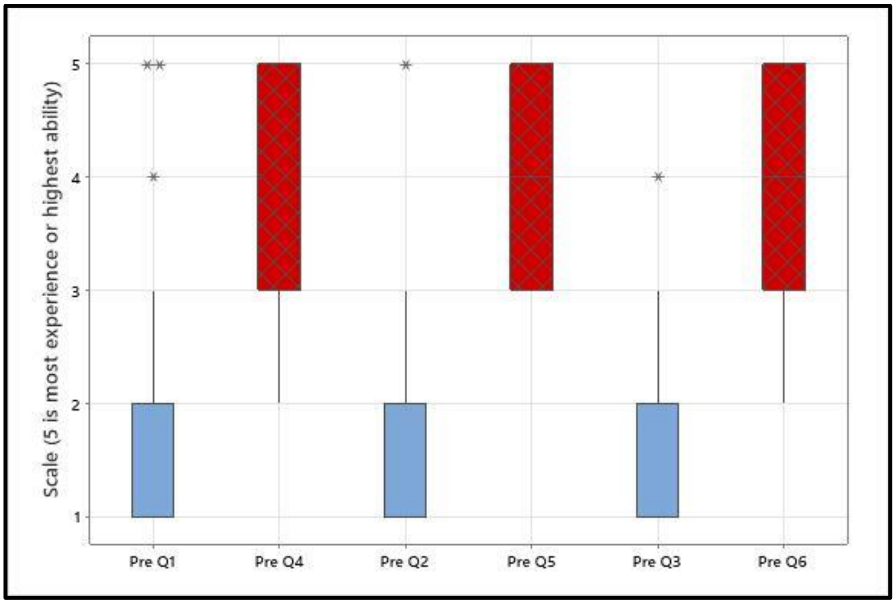

Figure 7.0 Techology Confidence: Experience (blue) vs. Ability to Learn (red/hatched)

The pre-survey indicates, however, that students, have much confidence in their ability to learn to use the Arduino hardware technology and supporting software. This is illustrated by the red hatched boxplots in Figure 7.0.

Comparison of the post- and pre-surveys indicate that, even though students showed initial confidence in learning to use the Arduino hardware, after learning to use it and applying it in the project, they showed a higher level of confidence with using the hardware than learning it (one-sided paired t-test of pre-question 6 vs post-question 1, p-value = .023, α = .05). Similar results did not occur with respect to confidence in learning and using the software. In this case there was no difference between learning confidence and ability to use confidence (two-sided paired t-test of combined pre-questions 7 & 8 vs combined post-questions 2 & 3, p-value = .81, α = .05). Table 2.0 summarizes the results of the statistical tests.

Table 2.0: Pre vs Post Confidence in Working with Technology

Question	Paired Test	Survey	Means	StDev	Diff Mean	Diff StDev	T-value	P-Value	α
Working with Arduino Hardware	One-sided	Pre	4.314	0.932	0.314	0.90	2.07	0.023	0.05
		Post	4.629	0.547					
Working with Software	Two-sided	Pre	4.105	0.609	0.038	0.93	0.24	0.810	0.05
		Post	4.143	0.801					

Thus, students did increase their confidence in using the Arduino hardware; however, the project had no effect on students' confidence in using the supporting software, which was already high (mean = 4.105, median = 4.333).

Hypothesis 2: Confidence in Independently Conducting Real-World Projects

With respect to Hypothesis 2, there is evidence that both the project and use of technology increased student confidence in working independently to address real-world problems. Questions 7 and 8 on the pre-survey and questions 4 and 5 on the post-survey were evaluated for this finding. These questions specifically asked the students to rate their level of confidence, using the 5-point Likert Scale, in their ability to

- Complete a hands-on project independently
- Translate lab lessons to "real-world" applications

When the responses for these questions were averaged per student, the one-sided paired t-test of means of pre-survey vs post-survey resulted in a p-value of .025, α = .05. Thus, there is evidence that students feel more confident after participating in and completing the real-world project independently.

The question is, however, whether students have increased confidence in both working independently and translating lessons to real-world problems or have just increased confidence in one of the two. To answer this question, the two questions were addressed independently. The result is that there is evidence students have increased their confidence in both working independently and translating lessons to real-world problems. However, the level of statistical confidence in working independently (α =0.05) is greater than that for translating lab lessons (α = 0.10). Table 3.0 summarizes the results of the statistical one-sided paired t-tests used to evaluate the two questions.

Table 3.0: Pre vs Post Confidence in Independently Conducting Real-World Projects

Question	Paired Test	Survey	Means	StDev	Diff Mean	Diff StDev	T-value	P-Value	α
Working Independently	One-sided	Pre	4.371	0.808	0.314	0.80	2.34	0.013	0.05
		Post	4.686	0.471					
Translating Lessons	One-sided	Pre	4.286	0.825	0.257	0.95	1.60	0.059	0.10
		Post	4.543	0.611					

How do GPA and Transfer Status Factor In?

It is interesting to note that there is evidence that students with major GPAs at or above 3.0 are experiencing an increase in confidence (p-value = 0.035, α = 0.05). The same is not true for students with major GPAs less than 3.0 (p-value = .108, α = 0.05). However, the samples sizes for GPA analysis are small (Ns are <30) so more data should be collected before any conclusions are identified.

The same analysis was completed for transfer students. The results indicate that there is no evidence to indicate a difference of change in confidence between transfer and non-transfer students. Again, the samples sizes are small, less than 30, so no conclusions can be drawn from this analysis.

There is evidence, however, of a difference between the major GPA of transfer and non-transfer students. Using a 1-way ANOVA test, at $\alpha = 0.10$, a p-value of 0.081 is calculated. Addressing this indication of difference, there is evidence, using the one-sided t-test, that the average GPA of non-transfer students is higher than the average GPA of transfer students (p-value = 0.04, $\alpha = 0.05$). Further data collection is necessary to investigate how this difference in GPA may translate to student confidence.

Conclusions and Recommendations

Based on the evaluation of the pre and post surveys, there is evidence that student confidence in using the Arduino hardware has increased, while the ability to use the two new pieces of software did not significantly improve. This was not a surprise as less focus was placed on actual programming, due to time limitations, with more emphasis placed on using existing programs.

The greatest take-away from this project for the instructors was the students' increased confidence in completing independent projects outside of the academic environment. Because the students taking this class are typically in their last year, this improved confidence could prove helpful whether they choose to continue in academia at a graduate level, or take an industrial position following graduation. While there is not as high an indicator that students were able to translate in class material into a "real-world" environment, some improvement was found. This suggests that more data is needed to determine the overall effect.

Finally, this study also pointed out several areas that may be explored in the future. As mentioned previously more data is needed to determine how effective this project is at increasing student confidence in translating in class material into "real-world" environments. More data is also needed to examine the effectiveness of this work with respect to transfer students as well as students with varying GPA's. The instructors are currently considering conducting a long-term study to gather more statistical data.

References

1. Neill, C. J., & DeFranco, J. F., & Sangwan, R. S. (2012, June), *A Study of Individual Learning in Software Engineering Team Projects* Paper presented at 2012 ASEE Annual Conference & Exposition, San Antonio, Texas. 10.18260/1-2—20866.
2. DeFranco, J. F., & Neill, C. J. (2013, June), *Improving Individual Learning in Software Engineering Team Projects* Paper presented at 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. 10.18260/1-2—19730.
3. Holland, Nathan, Brian Aufderheide, and Geddis Demetris, "Addition of Arduino Kits to Introductory Engineering Course" ASEE Southeast Section Conference, North Carolina State University, Raleigh, North Carolina. March 2019.
4. Belfadel, Djedjiga, Marcia Arambulo Rodriguez, Michael Zabinski, "Use of the Arduino Platform in Fundamentals of Engineering", ASEE Annual Conference and Expostion, Tampa, Florida. June 2019.

5. P. Jamieson and J. Herdtner, "More missing the Boat — Arduino, Raspberry Pi, and small prototyping boards and engineering education needs them," 2015 IEEE Frontiers in Education Conference (FIE), 2015, pp. 1-6, doi: 10.1109/FIE.2015.7344259.
6. Bedillion, M. D., & Muci-Kuchler, K. H., & Nikshi, W. M. (2018, June), *An Arduino-Based Hardware Platform for a Mechanical Engineering Sophomore Design Course* Paper presented at 2018 ASEE Annual Conference & Exposition, Salt Lake City, Utah. 10.18260/1-2—29774.
7. Elmer, J. J., & Kraut, D. A. (2018, June), *3-D Printing and Arduino in the Chemical Engineering Classroom: Protein Structures, Heat Exchangers, and Flow Cells* Paper presented at 2018 ASEE Annual Conference & Exposition , Salt Lake City, Utah. 10.18260/1-2—29653.