Effectiveness of a Theme-Based Introduction to Engineering Course

Aysa Galbraith, Heath A. Schluterman, Leslie Bartsch Massey, Candace Rainwater, and Brandon Crisel
University of Arkansas, agalbrai@uark.edu, hschlut@uark.edu, lbmassey@uark.edu, carain@uark.edu, bcrisel@uark.edu

Abstract - **The goal of this paper is to examine the effectiveness of changing to a theme-based, project-centric version of the Introduction to Engineering Course sequence by examining students' responses to end-of – semester evaluations, course evaluations, and retention within the college of engineering. The Freshman Engineering Program (FEP) at the University of Arkansas was established in 2007 with the primary objective of increasing the retention of new freshman in the College of Engineering (CoE) to their sophomore year. A key component of the FEP is the Introduction to Engineering course sequence which serves as the first year experience course for new students in the CoE. After seeing a decline in student participation in class, the Introduction to Engineering course sequence was redesigned to devote more time to theme-based, extended hands-on projects while redistributing the other topics. The four project themes Biosystems, Electronics, Robotics, and Structures- have been offered. Projects were developed to reinforce the engineering skills taught in the course, develop teamwork skills, incorporate engineering design, and guide teams to completion within the framework of the course. As a part of the end-of-semester evaluations, students are asked to rate certain aspects of the projects and course using a 5-point Likert scale. The responses were heavily in "strongly agree" and "agree" categories, with the mean total scores for all questions regarding student's improvement were fairly high and ranged from 3.86 to 3.97. The course evaluations show an increase in the mean of course ratings from 3.3 (before the implementation of projects) to 4.1 (after the implementation of projects). Retention rates has been improved since the start of the FEP, which can be attributed to the constant improvement of the format and the material offered through the program, including the restructuring of Introduction to Engineering course sequence.**

Index Terms – active learning, hands-on projects, introduction to engineering, theme based courses.

INTRODUCTION

The Freshman Engineering Program (FEP) at the University of Arkansas was established in 2007 with the primary objective of increasing the retention of new freshman in the College of Engineering (CoE) to their sophomore year. This objective supports college-wide retention and graduation rate goals. Thus far, there have been increases in both retention and graduation rates. Therefore, we believe we are providing our students with a solid foundation for success in engineering study.

A key component of the FEP is the Introduction to Engineering course sequence which serves as the first year experience course for new students in the CoE. The course sequence is offered as two, one-credit hour courses each semester of the first year. The students meet for two 50-minute lectures and one 50-minute drill section each week, as well as a 30-minute peer mentor meeting. This results in a total of 180 minutes of weekly contact. In general, drill sections focus on major selection and professional development, and peer mentor meetings focus on personal and academic success. Prior to Fall 2012, lectures focused mainly on engineering problem solving. After seeing a decline in student participation in class, the Introduction to Engineering course sequence was redesigned to devote more time to theme-based, extended hands-on projects while redistributing the other topics such as Engineering Problem Solving, Computer Skills, the Major Selection Process, and Professional Development. Since Fall 2012 semester, FEP has been offering the restructured Introduction to Engineering course sequence aimed at improving student engagement within the course. The original theme descriptions and project ideas are presented in earlier ASEE proceedings [1, 2]. The sections of Introduction to Engineering are divided into four themes: biosystems (formerly named biomechanical), electronics (formerly named computing), robotics, and structures. Students spend about half the semester working on activities and assignments associated with engineering skills, and the remainder of the semester is spent on the theme-based projects. The goals of these projects are to reinforce engineering skills taught in the course, develop teamwork skills, incorporate engineering design and maintain or increase interest in engineering. The themes and projects were designed to be multidisciplinary among the nine degrees offered by CoE.

THEME AND PROJECT DESCRIPTIONS

When students arrive for summer orientation, they are presented with a brief description of each theme and allowed to select their Introduction to Engineering course based on either theme preference or the time the course is offered during the fall semester. Students are required to register for a different theme to investigate for the spring semester. The number of sections of each theme vary by semester depending on expected demand, but there are typically three or four sections of each theme.

Below is a current description of each theme and its associated projects as written the FEP Playbook students receive at orientation:

- **Biosystems theme:** One of the Grand Challenges is to provide access to clean drinking water [4]. In this theme, students' first project is to develop a water filtration device using inexpensive materials that would be readily available in most places around the world. Before building a working prototype, students research methods for combining the given materials to make an effective filter to remove turbidity from a dirty water supply.

  The second project in this theme follows the grand challenge to engineer better medicines. In this project, students develop a mock drug delivery system and perform experiments to understand diffusion and the effects of mixing. Students use a photometer and a programmable microcontroller to analyze the effects of the various mixing techniques [3].
- **Electronics theme:** Electronics is the gateway for engineers to answer Grand Challenges such as reverse-engineer the brain and enhance virtual reality [4]. In this theme students build a series of simple circuits and control outputs using an Arduino Uno R3 Microcontroller. The projects assume that you have little or no prior experience. Students learn about basic programming paradigms including variables, input, output, loops, and conditional statements by modifying existing code. In addition, students learn basic theory from electrical circuits, including total resistance calculations, Ohm's Law, Kirchhoff's Laws, and voltage division, and then verify their calculations in a laboratory setting. This theme concludes with the implementation of a Button Hero game that involves the use of buttons, LEDs, wires, and resistors [3].
- **Robotics theme:** Robotics plays an integral role in many aspects of engineering including manufacturing, medicine, space exploration, and more. The use of robotics contributes to the Grand Challenge to engineer tools of scientific discovery [4]. In this theme, students use the Lego Mindstorm kits to build and program a simple robot. The projects assume that you have little or no prior experience. Though a series of tutorials, students learn about basic programming paradigms including loops and conditional statements. Students then apply their programming and problem-solving skills to solve engineering challenges [3].
- **Structures theme:** The focus in this theme is on the Grand Challenge to restore and improve urban infrastructure.[4] According to the 2017 Infrastructure Report card, 9.1% (1 in 11) of the nation's bridges were "structurally deficient" and 13.6% (more than 1 in 8) were "functionally obsolete" as of 2016 [5]. Therefore, the first project in the structures theme involves the use of simulation software to create a bridge that meets a set of design specifications while minimizing the cost of construction. Students then use the concepts they learn about structural members in tension and compression to complete a second project in which they build a balsa-wood structure. Students are given an opportunity to test and revise their designs prior to a competition [3].

ASSESSMENT

At the end of each semester, students are asked to complete an end-of-semester survey as their last assignment, which counts toward their grade. As a part of this survey, students rate certain aspects of the projects and course using a 5-point Likert scale and are allowed to leave additional comments and suggestions for improvement. Each semester since Fall 2012, students are given the following questions:

1) The projects associated with my Introduction to Engineering course theme improved my engineering problem-solving skills.
2) The projects associated with my Introduction to Engineering course theme improved my ability to communicate solutions to engineering problems.
3) The projects associated with my Introduction to Engineering course theme provided me with a meaningful experience working on a diverse team.
4) The projects associated with my Introduction to Engineering course theme helped me appreciate the multi-disciplinary nature of engineering.
5) The projects associated with my Introduction to Engineering course theme helped me appreciate the role of engineering in modern society.

Students were additionally asked the following two questions about their enjoyment of the projects:

6) I enjoyed the first theme-based project.
   - Biosystems - Sand Filter;
   - Electronics - Blinking Lights;
   - Robotics - Mindstorms Tutorials;
   - Structures - West Point Bridge Design
7) I enjoyed the second theme-based project.
   - Biosystems - Drug Delivery;
   - Electronics - Button Hero/Potentiometer;
   - Robotics - Green City Challenge;
   - Structures - Balsa Wood Structure.

RESULTS AND DISCUSSION

We analyzed the end-of-semester survey results, course evaluation results and retention data in order to conclude on the effectiveness of changing to a theme-based, project-centric version of the Introduction to Engineering Course sequence.

I. End-of-Semester Survey Results

Figures 1-5 show the results for the research questions listed above. The data is compiled over 10 semesters (from Fall 2012 to Spring 2017) in Introduction to Engineering I and II classes. The number of responses and calculated mean scores for each question are shown in Table I, and are also divided into themes to see if there is a bias for any theme. Mean scores are calculated assuming a point-scale where strongly disagree (SA) = 1, disagree (D) = 2, neither agree or disagree (NAD) = 3, agree (A) = 4, strongly agree (SA) = 5.

TABLE I: NUMBER OF STUDENT RESPONSES AND CALCULATED MEAN SCORES FOR EACH QUESTION SHOWN FOR EACH THEME AND AS TOTALS

Theme	# of Responses	Mean Scores Q 1	Q 2	Q 3	Q 4	Q 5
Biosystems	1050	3.65	3.81	3.93*	3.89*	3.93*
Electronics	934	3.98	3.92*	3.92*	3.97	4.05
Robotics	1032	3.86*	3.88*	3.90*	3.78	3.82
Structures	1155	3.95	3.95	3.97*	3.90*	4.07
Total	4171	3.86	3.89	3.93	3.88	3.97

Considering the total responses of all themes, the mean total scores for all questions regarding their improvement were fairly high and ranged from 3.86 to 3.97. However, some variances among the themes were observed. T-tests of question mean for each theme vs the question mean of the other themes was performed for each to test for significance. An alpha of 0.05 was used for all analyses. The marked values (*) were found to not be significantly different. Responses to each question are summarized in Figures 1-5.

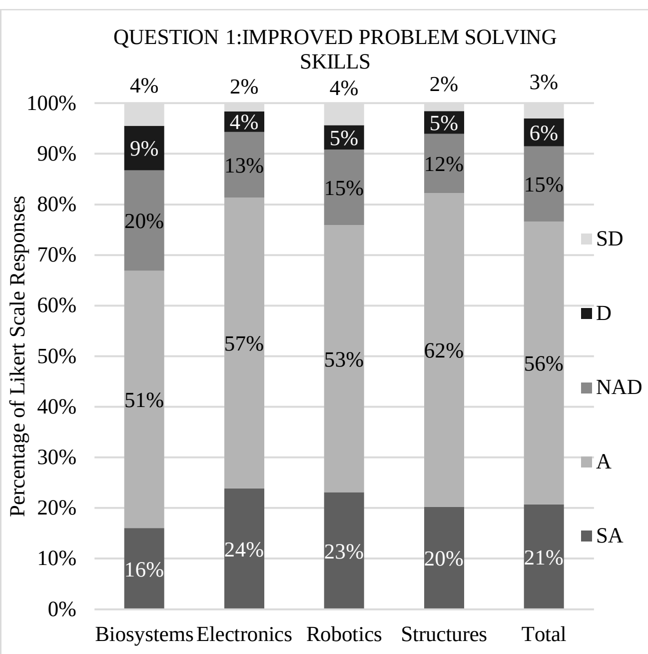

FIGURE 1: PERCENTAGE OF RESPONSES TO QUESTION 1 IN 5-POINT LIKERT SCALE DIVIDED INTO EACH THEME AND AS A TOTAL OF ALL THEMES.

While overall response to "improved problem solving skills" was good, Biosystems students responded significantly lower while Electronics and Structures scored significantly higher. The low responses for Biosystems may be related to the second (longer) project which is more related to collection and analysis of experimental data than solving a particular problem. Structures students on the other hand, experience competitions for both projects which by nature are more open ended and force them to continuously consider redesigning. Electronics students deal more with troubleshooting minor errors in wiring or code, so they feel they are redesigning.

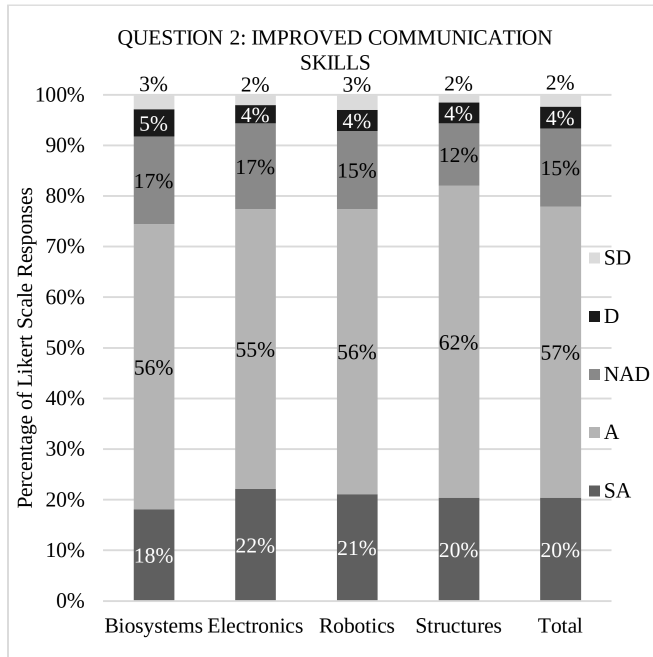

FIGURE 2: PERCENTAGE OF RESPONSES TO QUESTION 2 IN 5-POINT LIKERT SCALE DIVIDED INTO EACH THEME AND AS A TOTAL OF ALL THEMES.

Again the responses to "improved communication skills" are mostly agree or strongly agree. It is important to note that the question does not specify if written or oral communication skills are improved so student perspective of this question could vary based on the theme in which they participated. Structures is higher than the others which is surprising because these students do less analysis than other themes and therefore present mostly only qualitative ideas behind how they performed in the projects in writings associated with class assignments. However, students must frequently communicate their design ideas to teammates so that they can agree to and work toward the same design goal. Biosystems, as stated earlier, has the most analysis and structured presentation of results. Their lower responses might be a response to seeing some poor grades on their presentation of information. Also because of the nature of the Biosystems project, less oral communication is required between team members compared to the other themes to plan and execute the experiment.

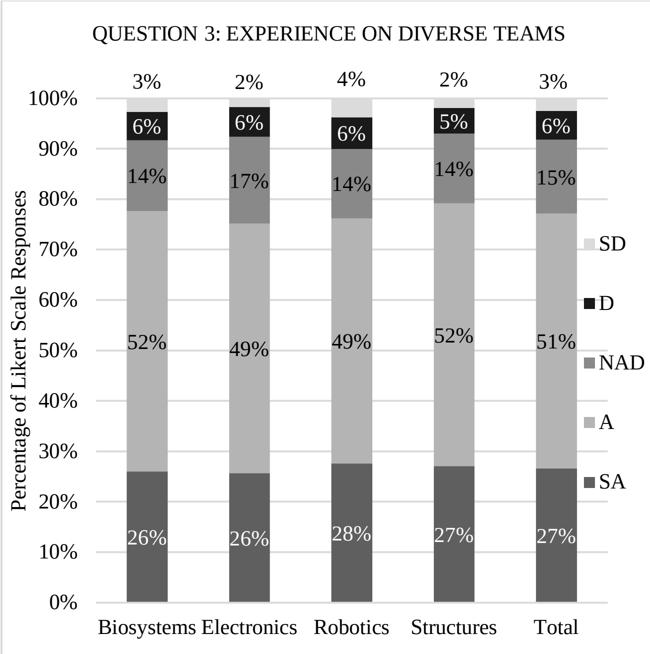

FIGURE 3: PERCENTAGE OF RESPONSES TO QUESTION 3 IN 5-POINT LIKERT SCALE DIVIDED INTO EACH THEME AND AS A TOTAL OF ALL THEMES.

The overall mean of 3.93 for the responses to "meaningful experience on diverse teams" is encouraging. The teams are always assigned by the instructor (not student selected) and usually by using random number generator or attendance rankings. There is no significant difference across themes as there is a significant difference in diversity among themes.

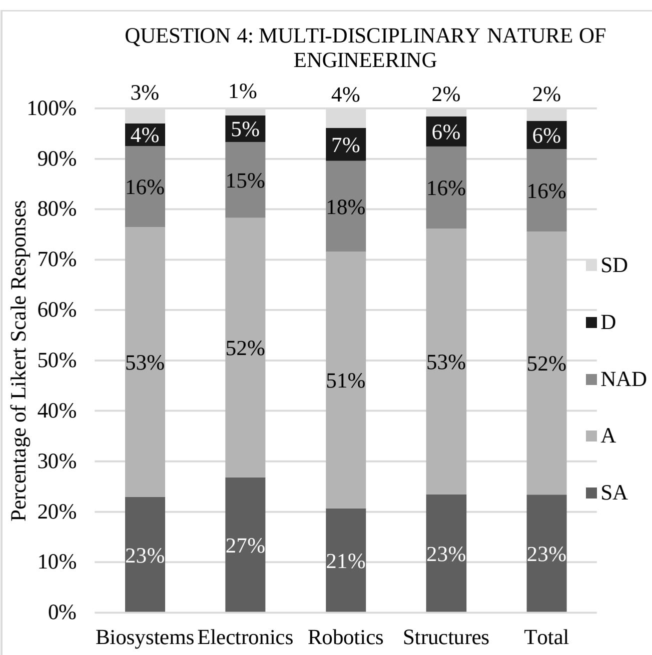

FIGURE 4: PERCENTAGE OF RESPONSES TO QUESTION 4 IN 5-POINT LIKERT SCALE DIVIDED INTO EACH THEME AND AS A TOTAL OF ALL THEMES.

The responses to "appreciate the multi-disciplinary nature of engineering" are mostly agree or strongly agree with a mean of 3.88. Electronics is higher than the others perhaps because students see the relation between Computer Science, Computer Engineering, and Electrical Engineering which are separate programs at this university. Robotics theme is surprisingly lower than the others. This theme combines more diverse fields of mechanical engineering with those that program. Perhaps because of the graphical interface used for Lego Mindstorms, students do not perceive the tasks as programming.

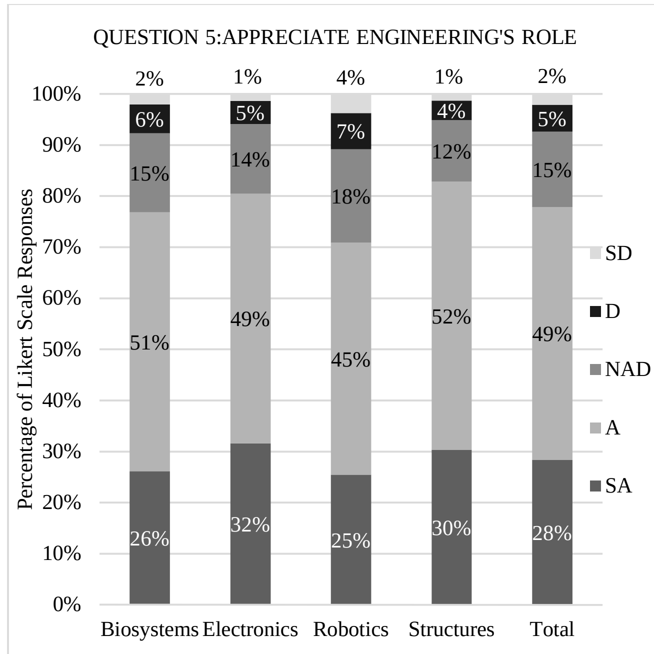

FIGURE 5: PERCENTAGE OF RESPONSES TO QUESTION 5 IN 5-POINT LIKERT SCALE DIVIDED INTO EACH THEME AND AS A TOTAL OF ALL THEMES.

The responses to "appreciate the role of engineering in modern society" have the highest mean at 3.97. Robotics has the lowest responses to this question at 3.82. This could be because the course has failed to make a connection between the project and a real world problem. The robotics project utilizes the Lego Green City Challenge which has a message related to energy conservation, but students do not really connect with this. They are simply trying to win a game and the tasks associated with the challenge do not make sense in the physical world. Electronics and Structures both score high on this question at 4.05 and 4.07 respectively. These themes more directly emulate situations students can relate to in the "real world". Electronics are of course ubiquitous and students begin to learn the basic ideas of wiring and programming that occur in their more complicated devices. Similarly, Structures students can easily make the connection between bridge design software and building a small structure to their "real world" counterparts.

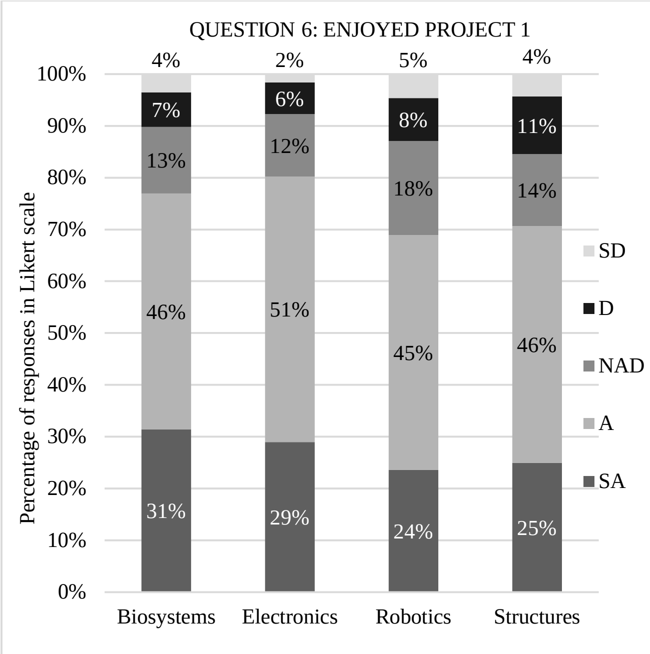

FIGURE 6: PERCENTAGE OF STUDENT RESPONSES TO THE QUESTION "I ENJOYED PROJECT 1" IN 5-POINT LIKERT-SCALE DIVIDED INTO THEMES. THE NUMBER OF RESPONSES ARE THE SAME AS QUESTIONS 1-5 AND ARE GIVEN IN TABLE I.

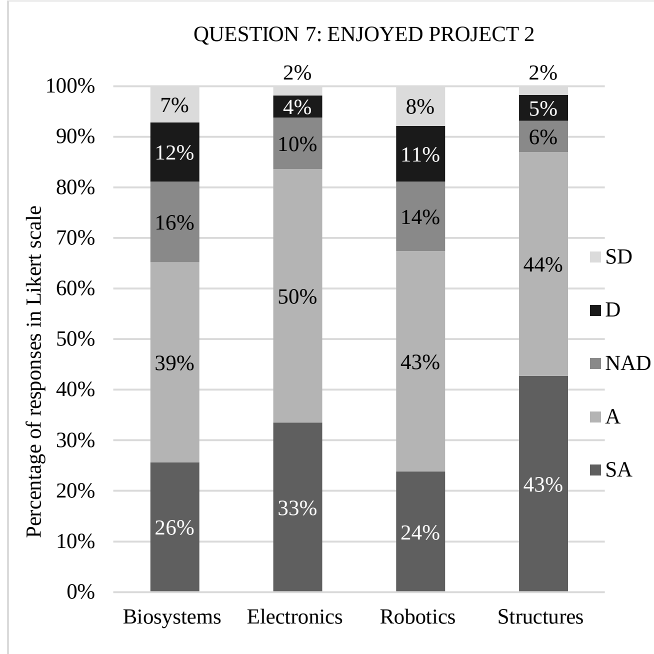

FIGURE 7: PERCENTAGE OF STUDENT RESPONSES TO THE QUESTION "I ENJOYED PROJECT 2" IN 5-POINT LIKERT-SCALE DIVIDED INTO THEMES. THE NUMBER OF RESPONSES ARE THE SAME AS QUESTIONS 1-5 AND ARE GIVEN IN TABLE I.

The overall mean of whether students enjoyed project 1 was 3.86. The themes are separated into Robotics (3.75) and Structures (3.76) which mean scores were lower compared to Biosystems (3.95) and Electronics (4.00) which had higher mean scores. These are likely somewhat dependent on their opinion of the second project since the students have finished both projects when they complete the questionnaire from which the data was collected. However, the results are as expected considering the nature of the projects conducted during project 1 in each theme. For example, the Biosystems project 1 (water filter) is likely more enjoyable to students because of the more competitive nature and clear real-world application of the project. Similarly, the electronics project is completely hands-on and while there is not competition between students in class, students likely take satisfaction in creating a circuit that completes the required project tasks. In contrast, the structures project 1 (West Point Bridge Design) likely scores as slightly less enjoyable because the project is computer based and students prefer the more hands on activity of project 2. There is no clear reason why students may find the robotics project 1 less enjoyable, except that during project 1 they are exploring how to control their robot by following specific programming instructions compared to project 2 where all programming is completely up to the students.

The overall mean of whether students enjoyed project 2 was 3.90. The themes are separated into Biosystems (3.65) and Robotics (3.64) which were lower against Electronics (4.09) and Structures (4.21) which were higher. Likewise, these are likely somewhat dependent on their opinion of the first project. Biosystems project 2 (Drug Delivery) involves repetitive experiments and analysis. Many students become bored with the same type of procedure. Robotics project 2 (Green City Challenge) scores low because students get bored with the trial and error approach to perfecting their robot performance or are frustrated with their final performance. Their robot does not perform tasks consistently, repeatedly and they therefore are frustrated by their scores. Electronics (Button Hero) is higher than expected given the analysis required during the final weeks. However, it is likely boosted by the fact that many students finish early and can actually miss class one to two days. Structures (Balsa Tower) scores the highest because it combines competition with little analysis. Students finish with the highlight of watching each structure destroyed.

II. Course Evaluation Results

We examined the course evaluations for Introduction to Engineering I and II courses from Fall 2007 to Spring 2017 in order to see the effect of implementing theme-based version on course ratings. The mean of course ratings (out of 5 possible points) from Fall 2007 to Spring 2012 (before the implementation of projects) is 3.30, and the mean of course ratings from Fall 2012 to Spring 2017 (after the implementation of projects) is 4.10. This is a very good indicator that the implementation of the projects have improved the students' experience in the Introduction to Engineering courses. The mean course ratings from Fall 2012 to Spring 2017 for the themes are as follows: Biosystems: 3.98, Electronics: 4.14, Robotics: 4.11, and Structures: 4.10.

It is worth noting that University of Arkansas has changed the method of delivering the course evaluations in Fall 2011. Prior to Fall 2011, students were given a chance to complete the course evaluations on paper during the last week of classes, whereas after Fall 2011, students were invited by email to complete the course evaluations online. This change caused a decrease in number of students completing the course evaluations and an increase in course ratings campus-wide. To our knowledge, university has not published an analysis on amount of increase in course ratings due to the change in method of delivering the course evaluations; therefore, we assume that part of the increase in the course ratings for Introduction to Engineering courses may be attributed to this method change, but we do not have data to make a quantitative conclusion.

III. Retention Rates

Table II shows the retention rates for College of Engineering and University of Arkansas. Mean retention rate for 1998 – 2006 represents the rates before FEP was established, mean retention rate for 2007 – 2011 represents the rates after FEP was established, and retention rates from 2012 to 2015 represent the rates after FEP implemented the theme-based Introduction to Engineering course.

TABLE II: RETENTION RATES FOR COLLEGE OF ENGINEERING (COE) AND UNIVERSITY OF ARKANSAS (UA) FOR 1998 – 2015 (NUMBER OF STUDENTS GIVEN BELOW THE YEAR IN PARENTHESIS.)

		1998 – 2006 COE (3306)	2007 – 2011 FEP (2333)	2012 FEP (771)	2013 FEP (673)	2014 FEP (712)	2015 FEP (802)
2nd yr Ret.	COE	62%	68%	72%	70%	71%	70%
	UA	82%	84%	85%	85%	84%	83%
3rd yr Ret.	COE	47%	56%	57%	58%	60%	
	UA	75%	75%	78%	75%	79%	
4th yr Ret.	COE	44%	51%	54%	55%		
	UA	71%	72%	74%	72%		
5th yr Ret	COE		49%	52%			
	UA		69%	71%			
6th yr Ret.	COE		49%				
	UA		67%				

Establishing FEP has improved the retention rates consistently over the years, which supports the primary goal of the program. There is further improvement in the rates since 2012, which may be attributed to the new format of the Introduction to Engineering course, but considering the effort of FEP staff to constantly improve all aspects of the program, we will not be able to give credit to the course format alone.

CONCLUSION

The University of Arkansas has implemented theme based projects in their Introduction to Engineering courses with mostly success. Some projects have been received better than others by the students, and some themes have better perceived efficacy than others. This information can be used to modify and improve projects in future semesters. While we cannot attribute the increases in course ratings and retention rates to the restructured, theme-based Introduction to Engineering course sequence alone, we can acknowledge the contribution of this improvement in the overall positive incline of these rates.

REFERENCES

[1] Schneider, K., H.A. Schluterman, C. R. Cassady, "Designing a Theme-Based Introduction to Engineering Course Sequence," Proceedings of the 2012 ASEE Midwest Section Conference, Rolla, MO 2012.

[2] Schneider, K., H.A. Schluterman, C. R. Cassady, "Student Perceptions of a Theme-Based Introduction to Engineering Course" Proceedings of the 2013 ASEE Midwest Section Conference, Salina, KS, 2013.

[3] University of Arkansas Freshman Engineering Program. "2017 Summer Orientation Playbook". May 2017

[4] National Academy of Engineering Grand Challenges for Engineering http://www.engineeringchallenges.org/

[5] America's 2017 Infrastructure Report Card http://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Bridges-Final.pdf

AUTHOR INFORMATION

Aysa Galbraith Instructor, University of Arkansas, agalbrai@uark.edu

Heath A. Schluterman Clinical Assistant Professor, University of Arkansas, hschlut@uark.edu

Leslie Bartsch Massey Instructor, University of Arkansas, lbmassey@uark.edu

Candace Rainwater Clinical Assistant Professor, University of Arkansas, carain@uark.edu

Brandon Crisel Instructor, University of Arkansas, bcrisel@uark.edu