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Increasing Student Learning and Interest in a Flipped First-Year Electrical & Computer Engineering Course

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Abstract

This paper describes an attempt to improve a first-year level digital circuits course by flipping the course and incorporating several active learning strategies. With the primary objective of increasing student interest and learning in digital circuits concepts, an integrated instructional design framework was proposed and utilized to provide incoming first-year engineering and technology students with practical knowledge of digital circuits. This research compared the effectiveness of the flipped course with the traditional course in areas of content coverage, student learning and performance, and their perceptions of a flipped first-year course. Through a experimental study, significance of flipped course is confirmed with positive outcomes such as higher course content, enhanced student performance on exams, and positive student perceptions of their learning experience. Furthermore, all students reported that they would enroll in a higher-level engineering course and the majority reported an increased interest in pursuing a degree in electrical or computer engineering.

1. Introduction

Meeting the challenges of an ever-changing engineering society/world in preparing future engineers has never been greater. On one hand, unprecedented progress in the field of electronics and programmable devices has provided an opportunity for engineers from all disciplines to accomplish their respective tasks at a much faster and easier pace. Accordingly, the majority of engineering programs are requiring all of their students to take at least one electrical engineering (EE) course[1]. However, on the other hand, some non-EE majors do not see the relevance of EE to their educational program until they face a real-world problem, often on-the-job after graduation, when the opportunity for learning applicable, real world skills or concepts in a course has already passed. Thus, one of the significant challenges engineering educators face is how to engage students of all engineering and technology majors in meaningful electrical & computer engineering activities that would encourage them to persist and pursue a career in engineering and technology.

Historically, incoming engineering and technology students had to work through a series of mathematics and other theoretical courses before they obtain the knowledge and skill set necessary to complete a meaningful technical project. This long wait time between students entering the engineering and technology (ET) program and when they have had the opportunity to apply content knowledge to a meaningful technical project does have a negative impact on the student enthusiasm and motivation to stay in the degree[2]. Identifying this challenge, several engineering educators have updated their curricula to engage students in hands-on design projects in the first-year curriculum. While this method potentially keeps students motivated, it is often difficult to find an engineering project that first-year students can succeed in, due to their limited technical knowledge and skills as they enter the ET programs. For example, many interesting and non-trivial engineering problems require a strong programming background or knowledge in advanced mathematics[2].

digital circuits however, is an area of electrical and computer engineering that requires more transferable skills such as quantitative reasoning, critical thinking, and problem solving versus advanced knowledge in calculus. Furthermore, as most of the incoming first-year students have grown in a culture of solid-state and point-and-click devices, and enter college without any knowledge of how these systems work, it is even more important to educate students on the inner working and applications of these circuits and systems.

2. Theoretical Framework

The proposed digital circuits course is designed for all incoming first-year ET students at Central Michigan University. In the past, this course has been taught in the traditional manner of two 75 minute classes, covering technical concepts such as Boolean algebra, logic function, truth tables, Karnaugh maps, combinational, and sequential circuits. While this course met the broad program objectives, and EE students were able to relate the concepts they learned to real-world applications, other students enrolled in the class were not able to comprehend the significance of this course in their respective curriculums.

Accordingly, to ensure an effective course redesign process, the instructional team utilized a combination of course design models[3-5]. Beginning with the end in mind or "backward design," a term introduced by Wiggins and McTighe[5], the course design process began by considering the significant understandings and skills first-year students need to gain prior to moving further into their respective ET curriculum. Based on this information, and in association with revised Bloom's taxonomy[6], the student learning objectives (SLO) for this course were updated to include the following.

- Gain awareness of electrical and computer engineering career opportunities.
- Reinforce critical thinking and problem-solving skills in engineering though team-based and hands-on experiences.
- Harness interpersonal skills through collaborative team projects.

Next, the course was examined through a theoretical lens of integrated course design[3] and the Technological, Pedagogical and Content Knowledge (TPaCK) model[4]. A situational analysis[3] was conducted to identify crucial factors that influenced the course design (e.g., course level, course format, accreditation requirements, curriculum or program-level goals, nature of the subject taught, characteristics of the learners, and characteristics of the instructor). Then, applying the TPaCK model, the "concept knowledge" required for students, which included essential course concepts, theories, ideas, and established practices in the discipline of engineering that are appropriate for first-year undergraduate students were identified. To increase student-faculty interactions, engagement, and promote effective learning and retention of core engineering concepts, specific teaching and learning strategies based on "pedagogical knowledge" and "pedagogical content knowledge" were evaluated. To provide an optimal learning environment, several technology based tools have been evaluated, and was sometimes a daunting task as most of the popular software programs were not designed for instructional use[4]. Broadly speaking, the "technological content knowledge" and "technological pedagogical knowledge" required for instructors and students in this course as well as the affordances and constraints of various technological learning tools were evaluated.

As a result, a variety of technology learning tools based on research associated with active and collaborative learning (e.g., Logisim, Chipcast, circuit testing equipment, Arduino microcontroller) and the inverted/flipped classroom techniques (e.g., video preview of classes, pre-class quiz, team-based hands-on activities, brief reflections, discussions on cutting-edge research and innovations) were introduced into the course. Further, overall structure and offering of the course had to be flipped as to encompass several aspects in the domains of technology, pedagogy, and content knowledge as presented in Figure 1.

3. Course Implementation

The course was evaluated over a period of two years, the first following traditional course (TC) format, and the second following flipped course (FC) format. Both of these courses were offered as a 3-credit class for first-year ET students, and met twice a week for 75 minutes each over a period of 15-week semester. The same instructor, using the same textbook, and similar homework and exams taught the courses. The course topics were introduced in the same order, and exams were conducted at approximately the same time during the semester.

A. Traditional Course

The digital circuits course was taught in the first-year using traditional course (TC) format. The class was composed of 24 first-year ET students, 22 males and 2 females, and served as the control group. Each class period lasted for 75 minutes, where the instructor taught technical concepts using Power Point slides and white board, and students copied the notes accordingly, per the schedule in Table 1. Occasionally, students were asked to solve problems on their own, with the instructor walking around the classroom to monitor student progress and to provide individual feedback. Most of the problems solved during class were obtained from the textbook, and students were encouraged to read the textbook periodically. Hands-on activities for digital circuits were introduced in a different follow up course.

Table 1: Traditional Course Weekly Outline

Week No.	Topics Covered	Week No.	Topics Covered
1	Significance of digital circuits, Number systems	9	Combinational Circuits
2	Boolean Logic, Logic Gates	10	Midterm-02
3	Switching Algebra	11	PLA, PAL, ROM
4	Simplification of Algebraic Functions	12	Latches & Flip Flops
5	Midterm-01	13	Finite State Machine
6	Karnaugh Maps	14	Finite State Machine
7	Karnaugh Maps	15	Final Exam Review
8	Combinational Circuits	16	Final Exam

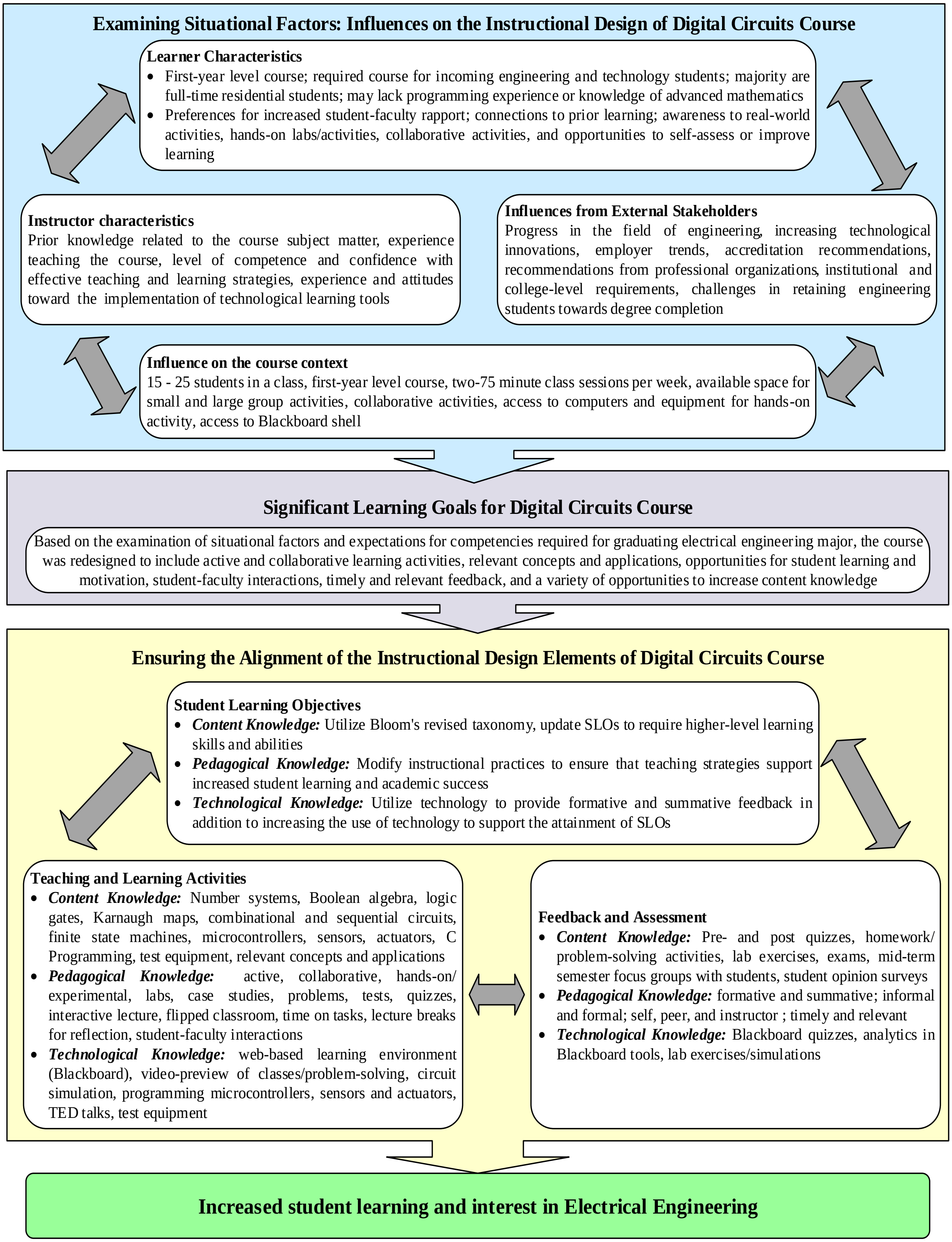

Fig. 1. Instructional design framework for the proposed digital circuits course

B. Flipped Course

The digital circuits course was taught during the second year using flipped course (FC) format, and composed of 16 first-year ET students, 14 males and 2 females, and served as the group who received intervention. Similar to the TC format, students and instructor met twice a week for 75 minutes in which the instructor used several pedagogical methods to teach course concepts. These methodologies included active and collaborative learning strategies infused in all the classroom activities, and critical thinking strategies infused in all student activities, both inside and outside classroom. The instructor served as the coordinator and organized all the educational activities in the classroom: preparing class videos, delivering lectures during class, forming student groups, providing timely student feedback, and directing the students to engage in hands-on design activities.

In order to encourage self- directed learning and also provide quality classroom time for active discussion, prior to attending each class, students were required to watch two-three videos (one-two class previews and one TED Talk each week) with a maximum total duration of 40 minutes[7]. These class videos (audio recording of instructor's voice and video recording of his screen) served as the first means of disseminating course material to the students[8], and provided a preview of course concepts through schematics, equations, and tables, to engage ET students who are typically visual learners[9]. In addition, to demonstrate the significance of ET, students were also asked to watch a specific TED talk[10] each week. Upon completion of watching these videos, students were required to take a short (5 questions) pre-class quiz to assess their respective understanding of the concepts. Scores from these pre-class quiz were used to identify concepts that were easy and difficult to the students, so that the instructor could effectively utilize the classroom time for active discussion and greater synthesis of course concepts.

During class, the first 10 minutes was utilized to reflect on what new information they have gathered from the TED talk. Topics of discussion from these videos ranged across: applications of circuits; theory behind the operation of a transistor; technical challenges in the design and implementation flapping wing aerial robot; open and closed loop control systems; autonomous self-driving cars; nano-quadrotors; miniature energy harvesters; self-aware robots; and classes where concepts behind each topic would be taught in their respective curriculum. The next 5 minutes of each class was used to briefly reflect what students have learned during the previous class, and answer any questions they typically might have. This brief reflection or pre-exposure formed an effective bridge as students learn new topics, thus aiding in knowledge retention[11].The next 50-55 minutes of the class was used to engage students in active learning through individual and group problem solving, demonstrations, and hands-on based activities as in Fig. 2.

The last 5 minutes of every class session was used to reflect on students have learned during that day, through an active learning strategy whereby students were asked to provide three key points that day, and one point that requires further clarification[12]. These key points stated by students were compiled on a weekly basis and provided to students through Blackboard, and served as a guide as they prepare for midterm and final examinations. After the class session, students were required to take a post-class quiz on Blackboard, and were tested on their abilities to solve problems on concepts taught during class. This post-class online quiz proved to be beneficial to both the students and instructor. The students benefited as they were able to get instant feedback on their responses and were able to attempt the question multiple times to secure the best grade possible. The analytics (mean score, average time spent by each student on a question, number of attempts for each question, etc.,) provided by Blackboard on these test scores helped the instructor assess student efforts, recognize difficult concepts, and gauge their understanding of course concepts, thus providing instant feedback to tailor the follow up class sessions without much effort and time. This systematic closed-loop educational process, helped the instructor better utilize the classroom time, flip the classroom to actively engage students, and teach more concepts as outlined in Table 2.

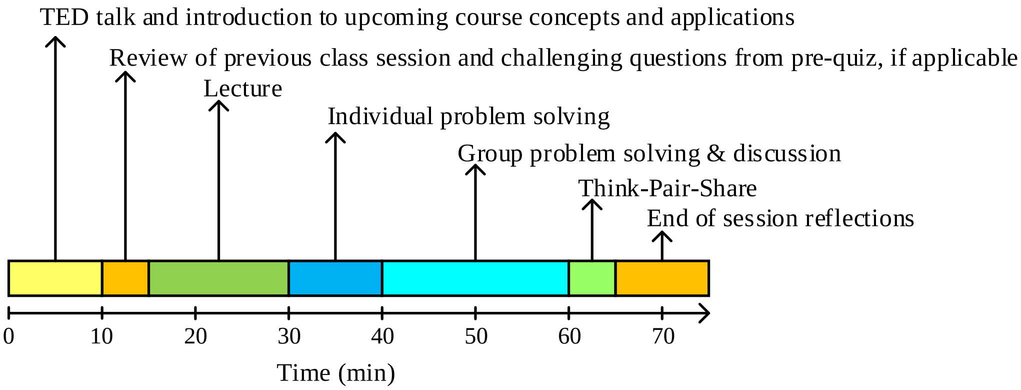

Fig. 2. In-class activities during a typical 75-minute FC session

Table 2. Flipped Course Weekly Outline

Week No.	Topics	Lab No.	Hands-on Activity
1	Significance of digital circuits & systems	0	Workshop on Collaborative Learning
2	Number Systems, Boolean Logic	1	Logic Gate Simulations
3	Logic Gates, Switching Algebra		
4	Simplification of Algebraic Functions	2	Logic Gate Verification
5	Midterm-01 & Karnaugh Maps		
6	Karnaugh Maps & Combinational Circuits	3	Delay & Frequency
7	Combinational Circuits	4	Implement a 3:8 Decoder
8	Latches, Flip Flop, Finite State Machine	5	Sprinkler System Automation
9	Finite State Machine		
10	Mock Exam & Midterm-02		
11	Microcontroller Programming	6	Temperature & Humidity Monitoring System
12	Sensors		
13	Actuators	7	Motion & Temperature Monitoring Alarm System
14	Interface logic gates & microcontroller	8	Security System Implementation
15	Lab & Mock Exam		

In addition, the FC also allowed students to get a better understanding of the course content through interactive workshops on collaborative learning, circuit simulation activities, hands-on design and implementation activities, rather than following an old-fashioned theoretical teaching approach. First, identifying the significance of collaborative learning in ET programs towards higher retention[13], the classroom activities have been designed to foster collaborative learning, and students were introduced to this concept through a workshop facilitated by the TLC from FaCIT. Second, hands-on design activities were designed in multiple focus aspects: encourage collaborative learning; demonstrate several theoretical concepts; built on previous activity; opportunity to be utilized for future activity; relate to a real-world scenario.

The lab activities not only taught students how to integrate different systems, but also taught valuable technical skills such as basics of analog to digital conversion through calibration of ultrasonic sensor, digital to analog conversion to play an alarm tune on a speaker, relation between program statements and their respective impact on controlling the environment, interfacing logic gates to microcontrollers without the necessitating a microcontroller with large number of inputs. Overall, the lab activities was particularly interesting for students as they could relate problems to real-world situations, and it appeared to boost their sense of pride from this accomplishment.

4. Results and Assessment

One of the most significant outcomes from this FC framework was that the instructor was able to increase the course content when compared to the traditional course. While one could state that this might be due to students spending more time on the course, it has been found that it was not the case. Students in the FC framework often reported spending less time outside classroom. This results suggest that, infusing active and collaborative learning activities into the first-year engineering curriculum utilizing an integrated instructional design framework does not require sacrificing any course content, but does allow students to gain more conceptual knowledge in a stress free environment.

Effectiveness of the FC was evaluated by comparing the content coverage, exam performance, and student perception of teaching, learning, and instructional methods. All procedures used to collect and compile data were approved by the university's Internal Review Board. The instructor utilized Bloom's Taxonomy[14] to develop higher-level learning objectives for all the pre-class and post-class quizzes and the exams. In addition, as the core learning objectives of TC and FC were the same, and exams were considered to be as similar as possible, the course is assessed based on student performances as presented in Table 3, with a similar strategy as suggested by Sahin[15].

One of the primary objective of the FC was to better teach the TC content, complete it ahead of time, and introduce new concepts into the course. Accordingly, the 15 week course content from the TC was flipped to complete in 10 weeks. In order to assess the impact of this FC framework, midterm examination grades are also presented in addition to the final grades in Table 3. A quick analysis of this data reveals that not only did the mean grade improved in the FC, the standard deviation also decreased in all midterms and final grade. It is also worthy to notice that, in addition to an improvement in the average FC grade, the range between the minimum and maximum grade for each exam reduced, highlighting a positive impact on student learning. In addition, the grade distribution in Fig. 3 shows that, the number of A/A-/B+ grades increased at the cost of B/B-/C+, and number of C-/D+ grades increased at the cost of E grades, further demonstrating the profound impact of the FC framework.

Table 3: Statistical Analysis of Examination Grades (N=Number of Students)

Group	**N**	**Mean**	**Std. Dev**	**Min**	**Max**
Traditional: Midterm-01	22	77.86	13.88	38.00	95.00
Traditional: Midterm-02		84.04	13.93	53.00	100.0
Traditional: Final		78.63	11.68	55.00	97.00
Traditional: Overall		79.72	12.63	44.98	91.63
Flipped: Midterm-01	16	88.33	8.55	70.00	97.00
Flipped: Midterm-02		95.37	6.62	82.00	100.0
Flipped: Final		83.68	9.75	65.00	100.0
Flipped: Overall		87.22	8.28	67.83	95.82

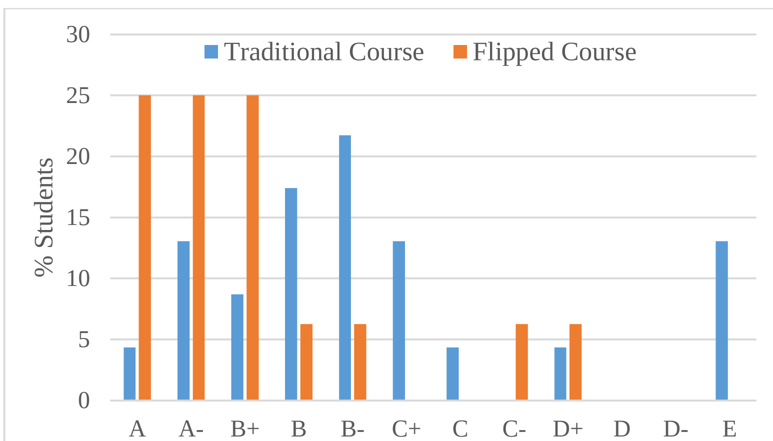

Fig. 3. Student Grade Distribution in Traditional and Flipped Courses

At end of the semester, students were also asked to provide their perceptions on additional aspects of the course learning environment through the several statements listed in Table 4. These statements were crafted to evaluate how the changes in the courses instructional design influenced student learning success. First, the fundamental goal of effectively combining the Technological Knowledge and Pedagogical Knowledge to deliver course content efficiently has been achieved as stated by the students. Next, student responses affirm attainment of SLOs, the effective use of active learning strategies, and suggest the potential for achieving the significant learning goals for a digital circuits course of retention and persistence in the field of engineering. Student comments related to the attention paid by the instructor align with the instructor characteristics as part of understanding situational factors that influence course design. The effective implementation of collaborative learning strategies where students work together towards a common goal building up on concepts learned in previous sessions boosted their confidence in interpersonal skills, ability to extrapolate theoretical concepts, and using critical thinking for problem solving, served to ensure alignment between SLOs and course feedback and assessment. Considered as a whole, the student responses affirm the effective use of an integrated instructional design framework to enhance student learning, motivation and interest in engineering.

Table 4. End of Semester Student Responses to FC

Statement	% Students Strongly Agree /Agree	Alignment with Instructional Design Framework (Fig. 1)
I am confident that I can extrapolate the theoretical concepts learned in this class to other subjects in higher classes	100	Student Learning Objectives
I am confident that I can extrapolate the quantitative reasoning skills learned in this class to other subjects in higher classes	100	
The collaborative activities have helped me increase my interpersonal skills	100	
I can identify the practical applications of Digital Circuits	90.9	Student Learning Objectives, Feedback and Assessment
The in-class handouts helped me learn in this class	100	Teaching and Learning Activities
The hands-on activities increased my knowledge of real-world applications of digital circuits	100	
The hands-on activities helped me to better understand course concepts	90.9	
I was more engaged in this class compared to other classes that I have completed at CMU	90.9	
The technology methods used (videos, quizzes, etc.) are easy to access	100	Teaching and Learning Activities; Feedback and Assessment
The hands-on activities are well aligned with coursework	90.9	
Based on my experience in this course, I would enroll in a higher-level engineering class that it is taught similarly	100	Developing Significant Learning Goals for digital circuits
I feel that use of integrated circuits, microcontrollers, actuators, and sensors is crucial in many engineering and technology applications	100	
Because of completing this course, my interest in pursuing a degree in Computer or Electrical Engineering has increased	72.7	
The instructor paid attention to our concerns through the semester	100	Examining Situational Factors

5. Conclusion

Leveraging on an integrated instructional design framework and utilizing several pedagogical methods and technology tools, a first-year digital circuits class for incoming engineering and technology students has been flipped. Goals of this course include improving students' awareness of electrical and computer engineering applications, reinforce their critical thinking and problem solving skills through team-based collaborative and active learning activities. Student performance and instructor perceptions were compared to the same course offered in the traditional lecture format, and results obtained from this research study was found to be promising.

Not only did this this flipped course method allowed the instructor to cover more content, but also helped students learn in an efficient manner, as evident through examination scores, and students-perceptions. Through the flipped method, students were able to identify the applications of digital circuits, perform simulations, and conduct experiments firsthand. As a result, they have a better grasp of the subject, and have a better understanding and significance of digital circuits. The proposed format became very attractive to students as they were able to see the benefits in their learning during a short span of time, and were better prepared for future courses in engineering disciplines.

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