2026 ASEE ANNUAL CONFERENCE June 21–24, 2026 | Charlotte Convention Center, NC
Host Sponsor UNC Charlotte
Paper ID #49992

Longitudinal Research on the Long-Term Impact of Flipped Learning on Engineering Student Success in Subsequent Courses

Dr. David O Johnson, The University of Kansas

David O. Johnson is a Teaching Professor in the Electrical Engineering and Computer Science department at the University of Kansas in Lawrence, KS, USA. He received his BSEE and MSEE from Kansas State University and his PhD in Computer Science from the University of Kansas. His research interests include human-robot interaction and natural language processing. He holds a patent on systems and methods for automated evaluation of human speech. Before beginning his academic career, he spent 31 years in industry as a manager, software developer, sales consultant and business analyst.

Longitudinal Research on the Long-Term Impact of Flipped Learning on Engineering Student Success in Subsequent Courses

Abstract

This longitudinal study investigates the long-term impact of flipped classroom instruction on engineering student success, with a specific focus on downstream academic performance and course completion. Over eight years, data were collected from 2,339 students enrolled in an introductory course in digital logic design, comparing outcomes between those who took the course in a flipped format versus a traditional or active learning format. The flipped classroom model restructures the learning environment by shifting content delivery to pre-class activities (e.g., videos, readings) and using class time for collaborative problem-solving. Prior research has demonstrated short-term benefits of flipped learning, including improved test scores and engagement. However, few studies have examined whether these benefits persist in prerequisite-dependent courses over time. Three studies were conducted involving three separate analyses of the same longitudinal dataset. Academic performance in the downstream courses was compared with the Mann-Whitney U test. Study 1 analyzed student performance in six subsequent engineering courses. Significant gains were observed only in a discrete structures course requiring foundational Boolean logic knowledge taught in the introductory digital logic design course. Study 2 focused on this course and found that students who took the flipped version of the digital logic design course consistently performed better in the discrete structures course across various demographic groups. Particularly notable were improvements among female, domestic, and White-Asian students. Study 3 examined DFW (D, F, Withdraw) rates in the digital design course itself, revealing a substantial decrease from 13% in the non-flipped format to 8% in the flipped format. Underrepresented and at-risk student populations—such as first-generation, BIPOC, and international students—saw some of the most significant reductions in DFW rates. While the flipped model did not impact performance in most downstream courses (likely due to weaker curricular alignment) the findings show that flipped learning in foundational engineering courses can improve performance in directly related subsequent courses and reduce course failure and attrition rates, especially for historically marginalized student populations. This study provides compelling longitudinal evidence supporting the strategic use of flipped learning in core engineering curricula to promote equity and student success.

Introduction

To understand the significance of this research, it's important to distinguish between three major instructional approaches: traditional lecture, active learning, and the flipped classroom [1] [2].

In the traditional lecture format, the instructor delivers content in a one-way manner, typically through in-class presentations or talks while students mostly listen, take notes, and absorb information passively. Interaction is limited, and direct application or practice of concepts usually happens outside of class as homework.

Active learning, on the other hand, places students at the center of the learning process. In this approach, instructors intersperse their teaching with interactive activities—such as group discussions, problem-solving sessions, or hands-on exercises—encouraging students to engage with the material, collaborate, ask questions, and apply their knowledge during class time. This method has been shown to enhance retention, understanding, and academic achievement because it fosters active participation and immediate feedback.

The flipped classroom combines elements of both approaches but rearranges the sequence of learning. Here, students are introduced to new concepts before class through pre-recorded lectures, readings, or other resources. Classroom time is then used almost exclusively for active, collaborative work on problems and projects, allowing students to clarify misunderstandings and deepen their understanding with instructor support and peer interaction. The flipped model thus maximizes opportunities for applied learning and immediate guidance within the classroom setting.

The flipped classroom model has been the focus of considerable research in engineering and technical education over the last decade. Many studies established its effectiveness in improving immediate course outcomes such as exam performance, conceptual understanding, and student engagement [3] [4] [5] [6] [7] [8] [9] [10] [11]. Other studies have found significant performance gains for under-represented groups and lower-performing students [12] [13].

The majority of studies on flipped learning in engineering have focused on short-term outcomes and lack the longitudinal data to definitively confirm long-term impacts. This study conducted over eight years involving over 2300 students contributes to this growing body of knowledge by systematically analyzing the downstream academic outcomes—specifically DFW rates and subsequent course performance—of students who experienced a flipped foundational digital logic design course, in comparison to those who participated in a traditional or active learning format. DFW rate stands for the percentage of students in a course who receive a grade of: D (poor performance, typically passing but not satisfactory for major requirements), F (failing), or W (withdrawal from the course). In other words, the DFW rate measures how many students did not successfully complete a course with a grade of C or better. This metric is often used by colleges and universities to identify courses that may need support or redesign, as high DFW rates can signal academic challenges or issues with course structure.

An earlier study measured the impact of a flipped course transformation on student learning and student success in a freshman level Electrical Engineering/Computer Engineering/Computer Science course, Introduction to Digital Logic Design [14]. This study is a comparison of student success in six courses which require an understanding of digital logic design as a pre-requisite. The comparison will be between students who took a flipped version of the Introduction to Digital Logic Design course and those who took an un-flipped version of the course. Additionally, this study examines the flipped vs. non-flipped DFW rate of students taking this course to determine if the positive results found in the earlier study continued.

Course Descriptions

Figure 1 shows the course map for the target course and six downstream courses:

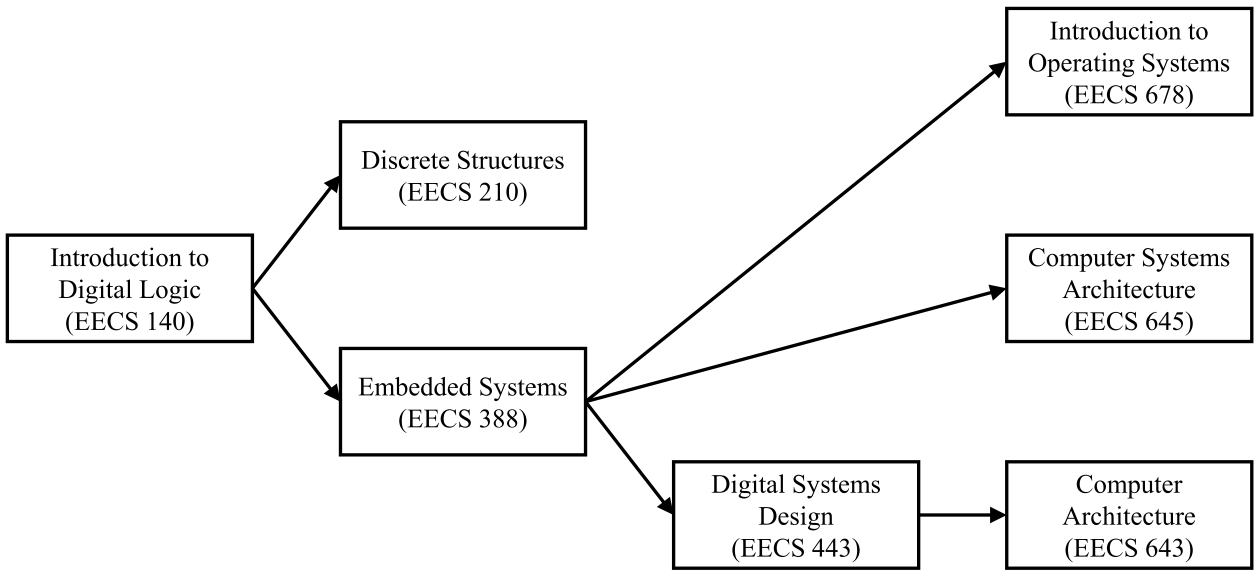

Figure 1 Course Map

Introduction to Digital Logic (EECS 140) Course Description: EECS 140 is an introductory course in digital logic circuits covering number representation, digital codes, Boolean Algebra, combinatorial logic design, sequential logic design, and programmable logic devices. The lecture portion of the course is taught in two formats. One is flipped following the format based on the SCALE-UP model [15] where students read, watch lecture videos, or review PowerPoint slides prior to class time and spend almost 100% of class time working on problems. More details on the flipped model can be found in [14]. The non-flipped version is taught in the traditional lecture or active learning mode depending on the instructor. The course includes a lab where basic soldering and Very High-Speed Integrated Circuit Hardware Description Language (VHDL) are taught. VHDL is a programming language used for describing the behavior and structure of digital circuits and systems. VHDL is mainly employed in the design and simulation of hardware, allowing engineers to model circuits before they are physically implemented.

Discrete Structures (EECS 210) Course Description: EECS 210 is an introduction to the mathematical foundations and techniques of computer science. Throughout, there is an emphasis on general reasoning, problem solving, and technical communication. Topics include basic proof techniques and logic, induction, recurrences, relations, number theory, basic algorithm design and analysis, and applications. The instructional method for the course varies by instructor, utilizing either traditional lectures or active learning approaches. It also includes a lab where students practice topics taught in the lecture section.

Embedded Systems (EECS 388) Course Description: This lecture and lab course addresses internal organization of micro-controller systems, sometimes called embedded systems, used in a wide variety of engineered systems. Topics include programming in C and assembly language, input and output systems, collecting data from sensors, and controlling external devices. This course focuses on one or two specific microprocessors, software development and organization, and building embedded systems. The course is taught through either lectures or active learning, depending on the instructor, and includes a lab for hands-on practice of lecture topics.

Digital Systems Design (EECS 443) Course Description: EECS 443 focuses on designing digital systems with hardware, implementing functional and control units using programmable logic devices, and introducing VHDL for modeling and designing these systems. The course utilizes a combination of traditional lectures and active learning methods, along with a lab where students can practice the topics covered in the lecture section.

Computer Architecture (EECS 643) Course Description: This course covers the structure and design of computing systems. It includes the examination and analysis of instruction set architectures, pipelined control and arithmetic units, vector processors, memory hierarchies, and performance evaluation. Traditional lectures and active learning methods are used throughout the course. There is no lab associated with this course. This course is targeted at Computer Engineering students.

Computer Systems Architecture (EECS 645) Course Description: This introductory course covers the design of single-chip microprocessors and systems. Topics include instruction set architecture, data path and control path design, pipelining, superscalar and out-of-order processors, memory hierarchy and management, multicore, caches, memory technologies, data parallel architectures, interrupts, and I/O structures. The course uses traditional lectures and active learning methods but does not include a lab. This course is for Computer Science students.

Introduction to Operating Systems (EECS 678) Course Description: This course aims to teach students to: identify common operating system services, define core system components, understand how these components interact, and analyze fundamental operating system problems. Programming assignments cover process creation, inter-process communication, system calls, process scheduling, and virtual memory. Laboratory exercises focus on tools and concepts for programming assignments and a few independent topics. The course uses both traditional lectures and active learning methods.

Student Performance Data Collection

Three studies were performed as described below using the letter grades which 2,339 students earned in these courses. All students took either the flipped or non-flipped version of EECS 140 (Introduction to Digital Logic). 117 students took EECS 140 more than once. For these students, the most recent grade received was used in calculating the DFW rate for the third study. The number of students taking EECS 140 each semester over the course of the studies is shown in Table 1. The demographics of the students are shown in Table 2. All demographics are self-reported except Transfer and International/Domestic. The University of Kansas uses the IPEDS definition for first-time students so, any other undergraduate students are considered Transfers. IPEDS defines a first-time student as a student who has no prior postsecondary experience (except as noted below) attending any institution for the first time at the undergraduate level. This includes students enrolled in academic or occupational programs. It also includes students enrolled in the fall term who attended college for the first time in the prior summer term, and students who entered with advanced standing (college credits earned before graduation from high school) [16].

Table 1 Students Enrollment During Study

Semester	Number of Enrolled Students
2016 Fall	119
2017 Fall	134
2017 Spring	98
2018 Fall	167
2018 Spring	110
2019 Fall	139
2019 Spring	143
2020 Fall	142
2020 Spring	136
2021 Fall	177
2021 Spring	143
2022 Fall	111
2022 Spring	162
2023 Fall	141
2023 Spring	188
2024 Spring	229

Table 2 Student Demographics

Demographic	Count
Gender	
Male	1914
Female	424
Unidentified	1
Race*	
AMIND	6
AMIND ASIAN HISPA WHITE	1
AMIND ASIAN WHITE	1
AMIND BLACK HISPA	2
AMIND BLACK HISPA WHITE	1
AMIND BLACK WHITE	2
AMIND HISPA	10
AMIND HISPA WHITE	8
AMIND PACIF	1
AMIND PACIF WHITE	1
AMIND WHITE	23
ASIAN	431
ASIAN BLACK	4
ASIAN BLACK PACIF	1
ASIAN BLACK WHITE	2
ASIAN HISPA	3
ASIAN HISPA PACIF WHITE	1
ASIAN HISPA WHITE	2
ASIAN PACIF	2
ASIAN PACIF WHITE	8
ASIAN WHITE	76
BLACK	91
BLACK HISPA	3
BLACK HISPA WHITE	2
BLACK WHITE	20
HISPA	36
HISPA PACIF WHITE	1
HISPA WHITE	139
NSPEC	146
PACIF	2
PACIF WHITE	1
WHITE	1312
Domestic vs. International	
Domestic	2066
International	273
Transfer student	
No	1957
Yes	382
First generation student	

No	2013
Yes	326
EECS 140 (Introduction to Digital Logic) Flipped vs. Non-Flipped	
Non-Flipped	901
Flipped	1438

*The standard race categories used by the US government, specifically the Office of Management and Budget (OMB), are: White, Black or African American, American Indian or Alaska Native, Asian, and Native Hawaiian or Other Pacific Islander. Additionally, the OMB recognizes two categories for ethnicity: Hispanic or Latino and Not Hispanic or Latino.

- AMIND – American Indian or Alaska Native
- ASIAN – Asian
- BLACK - Black or African American
- HISPA – Hispanic or Latino
- NSPEC – Not specified
- PACIF - Native Hawaiian or Other Pacific Islander
- WHITE - White

Study 1 – Downstream Course Performance Analysis

The first study compared the letter grades earned in the six downstream courses of the students who took the flipped and non-flipped version of the course. The letter grades were converted to grade points as shown in Table 3.

Table 3 Letter Grade Point Conversion

Letter Grade	Grade Point
A	4
A-	3.7
B+	3.3
B	3
B-	2.7
C+	2.3
C	2
C-	1.7
D+	1.3
D	1
D-	0.7
F	0
W	0
CR	2
NC	0

During the COVID pandemic semesters, students had the option of taking Credit (CR) or No Credit (NC) for a course. Less than 5% of the grades in this study were CR or NC.

An analysis of the data using four tests for normality (Shapiro-Wilk [17], Anderson-Darling [18], Lilliefors [19], and Jarque-Bera [20]) showed the data was not distributed normally. Consequently, the performance in the downstream courses was compared with the Mann-

Whitney U test [21]. The Mann-Whitney U test, also known as the Wilcoxon rank-sum test, is a non-parametric statistical test used to compare the means of two independent groups when the data is not normally distributed or when the sample sizes are small.

The results shown in Table 4 show that the mean grade of students taking the flipped version of EECS 140 (Introduction to Digital Logic) vs. the non-flipped version was only significant in the EECS 210 (Discrete Structures) course.

Table 4 Comparison of Student Success in Downstream Courses

	Flipped		Not Flipped		
Course	Mean	N	Mean	N	Significant (p value < 0.01)
Discrete Structures (EECS 210)	3.273	655	3.061	450	yes
Embedded Systems (EECS 388)	3.314	770	3.413	529	no
Digital Systems Design (EECS 443)	3.691	139	3.787	120	no
Computer Architecture (EECS 643)	3.820	15	3.080	5	no
Computer Systems Architecture (EECS 645)	3.320	458	3.224	307	no
Introduction to Operating Systems (EECS 678)	3.017	502	3.081	335	no

Study 1 – Downstream Course Performance Discussion

Initially, these results seem disappointing because the flipped course did not appear to improve student success in five of the downstream courses. However, further analysis shows why this makes sense. The six courses were chosen because initially it was thought that an understanding of digital logic was a prerequisite skill for them. But a more in-depth study of the course content reveals that this might not be the case.

Embedded Systems (EECS 388) covers programming in C and assembly language, input and output systems, collecting data from sensors, and controlling external devices. This course focuses on one or two specific microprocessors, software development and organization, and building embedded systems. None of this requires a deep understanding of digital logic.

Digital Systems Design (EECS 443) focuses on designing digital systems with hardware, implementing functional and control units using programmable logic devices, and introducing VHDL for modeling and designing these systems. A strong knowledge of VHDL is assumed to be a pre-requisite for this course. EECS 140 (Introduction to Digital Logic) teaches VHDL in the lab section of the course, but the lab section is taught independent of the lecture section. Therefore, it is logical that whether the EECS140 lecture section is flipped or not flipped would not have any impact on student success in EECS 388.

Computer Architecture (EECS 643) covers the structure and design of computing systems. It includes the examination and analysis of instruction set architectures, pipelined control and arithmetic units, vector processors, memory hierarchies, and performance evaluation. Computer Systems Architecture (EECS 645) covers similar topics including instruction set architecture, data path and control path design, pipelining, superscalar and out-of-order processors, memory hierarchy and management, multicore, caches, memory technologies, data parallel architectures, interrupts, and I/O structures. While computer architecture builds on the digital components discussed in EECS 140, these subjects are sufficiently distinct from the basic logic gate concepts covered in EECS 140. Therefore, success in EECS 140 is not necessarily indicative of performance in these courses.

Introduction to Operating Systems (EECS 678) teaches students to identify common software operating services, define core system components, understand their interactions, and analyze fundamental software problems, independent of the hardware concepts taught in EECS 140. Consequently, success in EECS 140 does not predict performance in EECS 678.

On the other hand, Discrete Structures (EECS 210) requires knowledge of basic proof concepts and Boolean logic, which are covered in EECS 140 (Introduction to Digital Logic). Therefore, doing well in EECS 140 likely influences success in EECS 210. The results of the Mann-Whitney U test (see Table 4) show that students who took the flipped version of EECS 140 did better in EECS 210 than students who took the version that was not flipped. Because the class format only impacted the performance in EECS 210 the second study focuses only on EECS 210.

Study 2 – Downstream Course Performance Analysis of Discrete Structures (EECS 210)

The second study analyzed the success of marginalized students in EECS 210 (Discrete Structures) who took the flipped version of EECS 140 (Introduction to Digital Logic) versus those who took the non-flipped version. The following groups of underrepresented students were studied:

- Female
- Non-white or non-asian
- International
- First generation to attend college
- Transfer student

Table 5 shows a comparison of male and female student success in EECS 210 (Discrete Structures). Significant differences are shown with a p-value in bold (alpha = 0.05). The comparison shows both males and females did better in EECS 210 when they took the flipped version of EECS 140 (Introduction to Digital Logic). It also shows females who took the flipped version did better than males with no significant difference between females who did not take the flipped version and males who took either the flipped or non-flipped version.

Table 5 Comparison of Student Success in EECS 210 (Male vs. Female)

Variable	N	Mean EECS 210 Grade Point	p
Male Flipped	533	3.227	**0.004**
Male Not Flipped	375	3.052	
Male Flipped	533	3.227	**0.004**
Female Flipped	122	3.473	
Male Flipped	533	3.227	0.777
Female Not Flipped	75	3.107	
Male Not Flipped	375	3.052	**<0.0001**
Female Flipped	122	3.473	
Male Not Flipped	375	3.052	0.285
Female Not Flipped	75	3.107	
Female Flipped	122	3.473	**0.036**
Female Not Flipped	75	3.107	

Table 6 shows a comparison of student success in EECS 210 (Discrete Structures) of White-Asian students versus Black, Indigenous, and People of Color (BIPOC) students. The two groups were divided based on self-reported races of the students as follows:

- White-Asian = WHITE, ASIAN, or WHITE ASIAN in Table 2
- BIPOC = Not WHITE, ASIAN, WHITE ASIAN, or NSPEC (race not specified) in Table 2

Significant differences are indicated by a p-value in bold (alpha = 0.05). The comparison reveals that White-Asian students who participated in the flipped version of EECS 140 (Introduction to Digital Logic) performed better in EECS 210 (Discrete Structures) than their counterparts who enrolled in the non-flipped version of EECS 140, as well as better than BIPOC students irrespective of the teaching method of EECS 140. The findings also demonstrate no significant difference in the performance of White-Asian students in EECS 210 based on the teaching method of EECS 140 when compared with BIPOC students. Furthermore, no significant difference was observed between BIPOC students who took the flipped version versus the non-flipped version. These results suggest that the flipped version of EECS 140 enhanced the academic success of White-Asian students in EECS 210 but did not significantly impact the performance of other student groups.

Table 6 Comparison of Student Success in EECS 210 (White-Asian vs. BIPOC)

Variable	N	Mean EECS 210 Grade Point	p
White-Asian Flipped	523	3.333	**<0.0001**
White-Asian Not Flipped	367	3.077	
White-Asian Flipped	523	3.333	**0.001**
BIPOC Flipped	84	2.989	
White-Asian Flipped	523	3.333	**0.015**
BIPOC Not Flipped	56	3.007	
White-Asian Not Flipped	367	3.077	0.414
BIPOC Flipped	84	2.989	
White-Asian Not Flipped	367	3.077	0.603
BIPOC Not Flipped	56	3.007	
BIPOC Flipped	84	2.989	0.909
BIPOC Not Flipped	56	3.007	

Table 7 shows a comparison of student success in EECS 210 (Discrete Structures) of domestic students versus international students (see Table 2). Significant differences are indicated by a p-value in bold (alpha = 0.05). The comparison indicates that both Domestic and International students who attended the flipped version of EECS 140 (Introduction to Digital Logic) performed better in EECS 210 (Discrete Structures) than Domestic students who attended the non-flipped version of EECS 140. Additionally, it demonstrates that International students enrolled in the flipped version of EECS 140 performed equivalently to those enrolled in the non-flipped version.

Table 7 Comparison of Student Success in EECS 210 (Domestic vs. International)

Variable	N	Mean EECS 210 Grade Point	p
Domestic Flipped	552	3.259	**0.001**
Domestic Not Flipped	402	3.046	
Domestic Flipped	552	3.259	0.428
International Flipped	103	3.346	
Domestic Flipped	552	3.259	0.967
International Not Flipped	48	3.188	
Domestic Not Flipped	402	3.046	**0.005**
International Flipped	103	3.346	
Domestic Not Flipped	402	3.046	0.176
International Not Flipped	48	3.188	
International Flipped	103	3.346	0.695
International Not Flipped	48	3.188	

Table 8 compares student success in EECS 210 (Discrete Structures) between first-generation college students and non-first-generation students (see Table 2). A significant difference is highlighted by a bold p-value (alpha = 0.05). The data shows that students who took the flipped version of EECS 140 (Introduction to Digital Logic) performed better in EECS 210 than those who took the non-flipped version, regardless of first-generation status. However, there was no significant difference among first-generation students who took the flipped versus the non-flipped version.

Table 8 Comparison of Student Success in EECS 210 (First Generation Students)

Variable	N	Mean EECS 210 Grade Point	p
Non-first-generation Flipped	566	3.293	**0.001**
Non-first-generation Not Flipped	404	3.072	
Non-first-generation Flipped	566	3.293	0.402
First-generation Flipped	89	3.145	
Non-first-generation Flipped	566	3.293	**0.010**
First-generation Not Flipped	46	2.965	
Non-first-generation Not Flipped	404	3.072	0.353
First-generation Flipped	89	3.145	
Non-first-generation Not Flipped	404	3.072	0.255
First-generation Not Flipped	46	2.965	
First-generation Flipped	89	3.145	0.125
First-generation Not Flipped	46	2.965	

Table 9 compares student success in EECS 210 (Discrete Structures) between transfer students and traditional students (see Table 2). A significant difference is highlighted by a bold p-value (alpha = 0.05). The comparison reveals that traditional students who participated in the flipped version of EECS 140 (Introduction to Digital Logic) performed better in EECS 210 (Discrete Structures) than those who enrolled in the non-flipped version of EECS 140, as well as better than transfer students, irrespective of the teaching method of EECS 140. The findings also demonstrate no significant difference in the performance of traditional students in EECS 210 based on the teaching method of EECS 140 when compared with transfer students. Furthermore, no significant difference was observed between transfer students who took the flipped version versus the non-flipped version. These results suggest that the flipped version of EECS 140 enhanced the academic success of traditional students in EECS 210 but did not significantly impact the performance of transfer students.

Table 9 Comparison of Student Success in EECS 210 (Transfer Students)

Variable	N	Mean EECS 210 Grade Point	p
Traditional Flipped	594	3.296	**0.001**
Traditional Not Flipped	374	3.099	
Traditional Flipped	594	3.296	**0.010**
Transfer Flipped	61	3.048	
Traditional Flipped	594	3.296	**0.002**
Transfer Not Flipped	76	2.876	
Traditional Not Flipped	374	3.099	0.529
Transfer Flipped	61	3.048	
Traditional Not Flipped	374	3.099	0.180
Transfer Not Flipped	76	2.876	
Transfer Flipped	61	3.048	0.545
Transfer Not Flipped	76	2.876	

Study 2 – Downstream Course Performance Discussion of Discrete Structures (EECS 210)

Study 2 evaluates the impact of flipping the EECS 140 (Introduction to Digital Logic) on student success in EECS 210 (Discrete Structures). Key findings indicate:

- Both male and female students performed better in EECS 210 after taking the flipped version of EECS 140, with females performing better than males overall.
- White-Asian students who took the flipped version also performed better than those who took the non-flipped version, and better than students from other ethnic groups.
- Both domestic and international students performed better in EECS 210 after taking the flipped version of EECS 140, with no significant difference observed among international students based on the teaching method of EECS 140.
- First-generation college students did better in EECS 210 after taking the flipped version of EECS 140, although there was no significant difference among first-generation students between the flipped and non-flipped versions.
- Traditional students outperformed transfer students in EECS 210, and traditional students who took the flipped version of EECS 140 performed better than those who took the non-flipped version.

Overall, the flipped version of EECS 140 improved student success in EECS 210 across various demographics.

Study 3 – DFW Rate Analysis of Introduction to Digital Logic (EECS 140)

The previous published study [14] measured student success in Introduction to Digital Logic (EECS 140) based on DFW rate (D/F/Withdraw). A comparison of the flipped and non-flipped version of the course showed significant improvements for females, Under-Represented Minorities (URM), and international students in DFW rate in the flipped version of the course.

The purpose of Study 3 here is to ascertain whether this improvement continued over the eight-year period of this longitudinal study.

Table 10 compares the DFW rate between the flipped and non-flipped versions of Introduction to Digital Logic (EECS 140) for all students (Overall) and the same groups of underrepresented students analyzed in Study 2 above. Figure 2 summarizes the results in Table 10

Table 10 Comparison of Introduction to Digital Logic (EECS 140) DFW Rates

	Not Flipped		Flipped		
Group	DFW Rate	N	DFW Rate	N	DFW Rate Difference
Overall	13%	901	8%	1438	5%
Female	14%	272	9%	152	6%
BIPOC	20%	237	12%	131	8%
International	10%	179	2%	94	8%
First Generation	24%	211	12%	115	13%
Transfer	8%	197	5%	185	3%

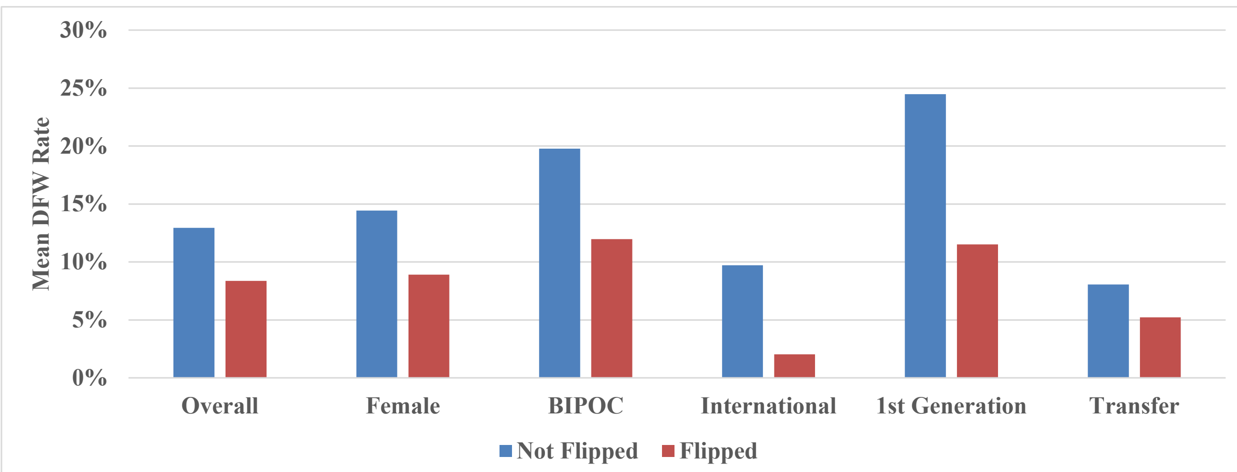

Figure 2 Comparison of Introduction to Digital Logic (EECS 140) DFW Rates

Study 3 – DFW Rate Discussion of Introduction to Digital Logic (EECS 140)

The DFW rate—representing the percentage of students who receive a D, F, or withdraw from the course—serves as a direct measure of student success in EECS 140 (Introduction to Digital Logic). A lower DFW rate indicates that more students are successfully completing the course by earning an A, B, or C. In the flipped version of EECS 140, the overall DFW rate decreased from 13% (the average across 8 semesters in the non-flipped format) to just 8% (across 10 semesters of the flipped format), demonstrating a marked improvement in student achievement and course completion. The DFW rate in the non-flipped semesters was slightly higher for females (14%) and significantly higher in the First Generation (24%) and BIPOC (20%) groups. The DFW rate for the flipped version of the course was reduced to only 9% for females. In the flipped version of the course, the DFW rate for First Generation was reduced to 14% and for BIPOC was reduced to 12%. International and Transfer students did better than the general population in both the flipped and non-flipped version of EECS 140 but still did better in the flipped version than in the non-flipped version.

Conclusions

The aim of this longitudinal research was to assess whether the results of an earlier study [14] persisted over an extended period. The research comprised three separate studies. Study 1 examined student performance across six subsequent engineering courses, with significant improvements observed only in a discrete structures course. Study 2 concentrated on this course and revealed that students who had taken the flipped version of the digital logic design course consistently outperformed their peers in the discrete structures course across multiple demographic groups. The earlier study also showed that DFW rates for certain demographic groups were significantly lower among students who experienced the flipped format. Study 3 sought to determine whether these improvements were sustained throughout the eight-year duration of the longitudinal study.

These three studies showed that the flipped version of EECS 140 (Introduction to Digital Logic) led to:

- Significant improvement in grades for EECS 210 (Discrete Structures) for most student groups, especially females, White-Asian, domestic, and traditional students.
- Significant reduction in DFW rates in EECS 140 for all students, with especially notable gains among underrepresented, international, and first-generation students.
- No measurable impact on student success in most other downstream courses, likely due to the nature of their content.

The studies suggest that flipping EECS 140 provides clear, positive effects on student success in directly related courses (EECS 210) and improves overall course completion rates in the target course (EECS 140), particularly for students from underrepresented backgrounds.

One limitation of this research is that it focused on predefined demographic groups rather than categorizing students by overall academic performance, such as final GPA using quartiles, percentiles, or standard deviation groupings. Future studies could address this by examining performance-based groupings. For example, exploring whether students in the lowest-performing group benefit more from the flipped format than those in higher-performing groups, regardless of demographic classification.

References

[1] R. M. Felder, D. R. Woods, J. E. Stice, and A. Rugarcia, "The future of engineering education II. Teaching methods that work," *Chemical Engineering Education,* vol. 34, pp. 26-39, 2000.

[2] S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt*, et al.*, "Active learning increases student performance in science, engineering, and mathematics," *Proceedings of the National Academy of Sciences,* vol. 111, pp. 8410-8415, 2014.

[3] B. Kerr, "The flipped classroom in engineering education: A survey of the research," in *2015 International Conference on Interactive Collaborative Learning (ICL)*, pp. 815-818, 2015.
[4] J. Bishop and M. A.Verleger, "The flipped classroom: A survey of the research," in *2013 ASEE annual conference & exposition*, pp. 23-1200, 2013.
[5] M. K. Seery, "Flipped learning in higher education chemistry: emerging trends and potential directions." in *Chemistry Education Research and Practice*, vol. 16.4, pp. 758-768, 2015.
[6] K. F. Hew, S. Bai, W. Huang, P. Dawson, J. Du, G. Huang, C. Jia, and K. Thankrit, "On the use of flipped classroom across various disciplines: Insights from a second-order meta-analysis," *Australasian J. Educ. Technol.*, vol. 37, no. 2, pp. 132–151, 2021.
[7] A. Karabulut-Ilgu, N. Jaramillo Cherrez, and C. T. Jahren, "A systematic review of research on the flipped learning method in engineering education," *British Journal of Educational Technology*, vol. 49, no. 3, pp. 398-411, 2018.
[8] M. I. Baig and E. Yadegaridehkordi, "Flipped classroom in higher education: a systematic literature review and research challenges," *International Journal of Educational Technology in Higher Education*, vol. 20, p. 61, 2023.
[9] J. Moraros, A. Islam, S. Yu, R. Banow, and B. Schindelka, "Flipping for success: evaluating the effectiveness of a novel teaching approach in a graduate level setting," *BMC Medical Education*, vol. 15, p. 27, 2015.
[10] B. P. Etemi, H. Uzunboylu, S. Latifi, and U. Abdigapbarova, "The Effect of the Flipped Learning Approach on Engineering Students' Technology Acceptance and Self-Directed Learning Perception," *Sustainability*, vol. 16, no. 2, p. 774, 2024.
[11] C. K. Lo and K. F. Hew, "The impact of flipped classrooms on student achievement in engineering education: A meta-analysis of 10 years of research," *Journal of Engineering Education*, vol. 108, no. 4, pp. 523-546, 2019.
[12] Q.-V. Dang and D. D. Gajski, "Bringing in-class online-A hybrid solution," in *Fourth Interdisciplinary Engineering Design Education Conference*, pp. 12-17, 2014.
[13] J. A. Roberts, A. N. Olcott, N. M. McLean, G. S. Baker, and A. Möller, "Demonstrating the impact of classroom transformation on the inequality in DFW rates ("D" or "F" grade or withdraw) for first-time freshmen, females, and underrepresented minorities through a decadal study of introductory geology courses," *Journal of Geoscience Education*, vol. 66, no. 4, pp. 304-318, 2018.
[14] D. O. Johnson, M. A. McVey, and C. P. Melgares, "The Impact of Course Transformation on Student Learning and Success in Fundamental Electrical Engineering/Computer Science Courses," in *2019 ASEE Annual Conference & Exposition , Tampa, Florida*, 2019.
[15] R. J. Beichner and J. M. Saul, "Introduction to the SCALE-UP (student-centered activities for large enrollment undergraduate programs) project," *Proceedings of the International School of Physics "Enrico Fermi," Varenna, Italy,* 2003.
[16] U.S. Department of Education, National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS), 2024.
[17] S. S. Shapiro and M. B. Wilk, "An Analysis of Variance Test for Normality (Complete Samples)," Biometrika, vol. 52, no. 3/4, pp. 591–611, 1965.

[18] T. W. Anderson and D. A. Darling, "Asymptotic theory of certain ‘goodness-of-fit’ criteria based on stochastic processes," Annals of Mathematical Statistics, vol. 23, no. 2, pp. 193–212, 1952.

[19] H. W. Lilliefors, "On the Kolmogorov-Smirnov Test for Normality with Mean and Variance Unknown," Journal of the American Statistical Association, vol. 62, no. 318, pp. 399–402, 1967.

[20] C. M. Jarque and A. K. Bera, "A Test for Normality of Observations and Regression Residuals," International Statistical Review, vol. 55, no. 2, pp. 163–172, 1987.

[21] H. B. Mann and D. R. Whitney, "On a test of whether one of two random variables is stochastically larger than the other," Annals of Mathematical Statistics, vol. 18, no. 1, pp. 50–60, 1947.