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Systematic Review of Intervention Strategies in Introductory Circuits Education: Insights from ASEE Conference Papers from 2014 to 2023

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Abstract

Circuits is one of the fundamental subjects for many engineering majors and learning its fundamental concepts is essential for most engineering undergraduate students, especially with the increasing reliance on electronic systems in the design, testing, and implementation of engineering solutions. While some systematic reviews on circuits education have been conducted, previous reviews have been restricted in scope, such as not including more recent publications and excluding certain modes of instruction, such as online teaching. Thus, the engineering education community could benefit from an intentional broad examination and review of contemporary interventions in the teaching of circuits for undergraduate engineering students. Specifically, we investigated what kinds of interventions were conducted in circuits education and what impact these interventions had on students, such as engagement, knowledge, and course grades in the course. To accomplish this, we conducted a systematic review by searching and filtering American Society for Engineering Education Conference papers from 2014 to 2023. Specific keywords search, forward and backward snowballing were used to locate 32 papers that included 44 studies overall. Moreover, types of interventions and learning environments were categorized to determine their effects on students. This study holds significant importance since learning circuits concepts can be complex, but it is essential for engineering students to master. Also, this study is expected to empower instructors to make changes in their classrooms, leading to better learning outcomes for their students.

Keywords: Circuits, Intervention, Engineering Student, Electrical Engineering, Instructional Strategies

I. Introduction

Circuits is a fundamental subject for many engineering majors. For most engineering undergraduate students, understanding the fundamentals of circuits is crucial, particularly given the growing importance of electronic systems in the development, testing, and application of engineering solutions. Therefore, the importance of circuits for engineers, especially electrical engineers, cannot be understated [1].

Under these circumstances, there have been a wide variety of reported interventions through the American Society of Engineering Education (ASEE) annual conference proceedings. Accordingly, becoming familiar with new interventions in teaching circuits will result in empowering instructors' knowledge on instructional strategies and improving student learning of circuits concepts. Also, the need to determine the impacts that these interventions could have on students' performance in the classroom has great importance as well. There have been so many studies on how to teach electrical concepts but since the concepts taught in electrical engineering are rather complex, more studies on methods of teaching electrical engineering are needed [2].

As circuits is one of the fundamental subjects in undergraduate engineering studies, it is important to identify these interventions along with the noted gaps in previous studies. This identification is crucial for both students and instructors as it allows for an understanding of the impacts these interventions have on students' performance and their effectiveness in improving student learning. Therefore, in this paper, we conducted a systematic review of 32 conference papers published in the last 10 years of ASEE annual conference proceedings on the subject of interventions in introductory circuits courses for undergraduate engineering students. Some of the papers included more than one study about interventions, bringing the total number to 44 studies out of 32 conference papers.

Purpose of the Study

This study intends to find answers to the following questions: What kinds of interventions for circuits education have been reported through American Society for Engineering Education (ASEE) Conference proceedings in recent years?; and what impact did these interventions have on student performance?

II. Background Literature

Circuits Education in the United States

The introductory circuits course, which is usually offered in the second year of many engineering programs, is not just for electrical engineering students. Based on the curriculum of universities, this course might be counted as a "gateway courses" for some fields of engineering, such as Aerospace Engineering, Chemical Engineering, Civil Engineering, and Mechanical Engineering. The term "gateway courses" refers to courses that are required by a program as considered as a foundational course and have high enrollment and high failure risk [3]. The name for such introductory courses could vary depending on the university, but most of the accepted course names which include teaching the concepts of introductory circuits are as follows: Linear Circuit Analysis, Circuits and Devices, Analog Systems and Circuits, Circuit I, Analog Circuit Design and so on.

Types of Interventions

Interventions are specific activities or sets of activities that are designed and implemented to address educational problems [4]. According to Harackiewicz and Priniski (2018), interventions can be divided into three different groups. The first group is called motivational intervention with three categories: (a) task value interventions, (b) framing interventions, and (c) personal value interventions [4]. According to Pressley et al. (1989) [5], the second group is called learning strategies interventions defined as identifying and implementing the right processes to help facilitate students' performance on a given task. This intervention has three categories as well: (a) cognitive strategies, (b) metacognitive strategies, and (c) management strategies [6]. The third group is practice-based and/or research-based instructional strategy (PBRBIS) interventions which include but are not limited to conceptual change strategies, cooperative and collaborative learning, discovery learning, flipped classrooms, inquiry-based learning, peer-led instruction, problem-based learning, case-based learning, and technology-enhanced learning [7]. As these categories originate from different authors, it is a possibility that their concepts are not mutually exclusive.

Previous Systematic Reviews

A systematic review of interventions in introductory circuits education is not a new approach. By searching the journals and conference papers for the past 10 years, we identified three systematic reviews on this subject, all of which were published in ASEE Conference proceedings. Pitterson and Streveler (2016) systematically reviewed 12 papers about the types of activities used to teach circuits, the perceptions of students about those activities, and the effects of the learning environment on their learning. They discovered a variety of activities employed to keep students interested in both lecture and lab classes and reported an increase of student learning in all but one of the cases [8].

Espera and Pitterson (2019) investigated 13 papers which used evidence-based instructional practices in teaching circuits concepts across undergraduate engineering education and science fields. They concluded that there is evidence supporting the effectiveness of the methods outlined in the examined papers for promoting the learning of circuit concepts. They did acknowledge that much more needs to be done in terms of recording and evaluating the general efficacy of intervention strategies on students' outcomes. Furthermore, they discovered that the use of real and virtual experimentation environments is the most engaging learning experience for students in learning circuit concepts [9].

Reagan et al. (2020) also conducted a systematic review of 30 papers on the best methods for teaching basic circuits. They found that emphasizing students' creation of knowledge, utilizing active learning strategies as opposed to traditional lectures, and employing project-based learning increases motivation with differing impacts on learning [10].

While the systematic reviews mentioned above provided valuable insights into interventions in circuit education beneficial for undergraduate students, the gaps that were found in them is as follows: not including the category or sub-category of interventions [8], [9], [10], using physics class for interventions as well as circuits class [8], [9], using only in-person interventions [10], and only recording students' perception of the success of interventions [8].

Due to the aforementioned importance of circuits education, becoming familiar with new interventions in teaching circuits will result in empowering students' knowledge and improving the learning of these concepts. Also, the need to determine the impacts that these interventions could have on students' performance in the classroom and in learning these concepts is of great importance as well. There have been so many studies on how to teach electrical concepts but since the concepts taught in electrical engineering are rather complex, more studies on methods of teaching electrical engineering are needed [2]. Moreover, since these systematic review studies are not gathered in one study and the variety of interventions found is numerous, finding and learning all these interventions for instructors can be frustrating.

III. Method

For better accuracy and precision, a combination of methods guided by Cooper [11], Cochrane's book [12], and Borrego et al. [13] was used for this systematic review. The step-by-step framework which was used in this study is as follows: (a) develop inclusion and exclusion criteria, (b) implement search strategies for the literature, (c) screen the articles based on the abstracts and inclusion and exclusion criteria, (d) develop the coding themes, (e) analyze and integrate the outcomes of studies, and (f) interpret the evidence.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria for ASEE conference papers were as follows: (a) articles should have been published in English from 2014 to 2023, (b) interventions should be done for undergraduate students in higher education, (c) work-in-progress papers were excluded from this study due to unavailability of their final results, and (d) interventions should be done in an introductory circuits course or another course that focuses on introductory circuits topics.

Searching Strategies for the Literature

Since the focus is on ASEE Conference papers, this study narrowed the search to only the ASEE website and used three methods to locate articles related to the interventions in circuits education. First, keywords were used to strategically search the ASEE publications database located in the *Publications and Media* tab, under the heading *Conference Papers-PEER*. Since the papers which are published in this conference are open-sourced, there was no need to use other resources for searching papers. Another reason for choosing the ASEE website rather than other search tools was that, when used, other resources yielded a large number of unrelated results rather than focusing on ASEE Conference papers. Also, those relevant publications identified were still accessed via the ASEE PEER database, compromising the usefulness of alternative search tools. Search terms for ASEE PEER papers from 2014 to Jan 2023 is summarized in Table 1.

Table 1. Keywords Used for Search in ASEE PEER

Keywords used	Search results
"circuits"	2850
"circuits" AND "teaching"	2535
"Circuits" AND "teaching" AND "introduction"	1484
"circuits" AND "teaching" AND "introduction" AND "Outcomes"	972
"circuits" AND "teaching" AND "introduction" AND "Outcomes" AND "undergraduate"	779

A second strategy was checking the references of the papers that were found, often called backward snowballing [14]. The references of each article were explored in order to find other ASEE Conference papers used as references in each article to reduce the possibility of missing an article related to the study [14]. All the inclusion and exclusion criteria mentioned earlier applied to the articles found in this part as well. The number of articles that were overlooked was not that high as only 3 articles were found in this regard.

The final strategy was checking if each located article was cited by other articles, which is often called forward snowballing [14]. Each article was checked separately to find ASEE Conference papers which were overlooked as well. In this part, only 2 articles were acceptable for this study based on the inclusion and exclusion criteria. Figure 1 shows how articles were identified based on each strategy.

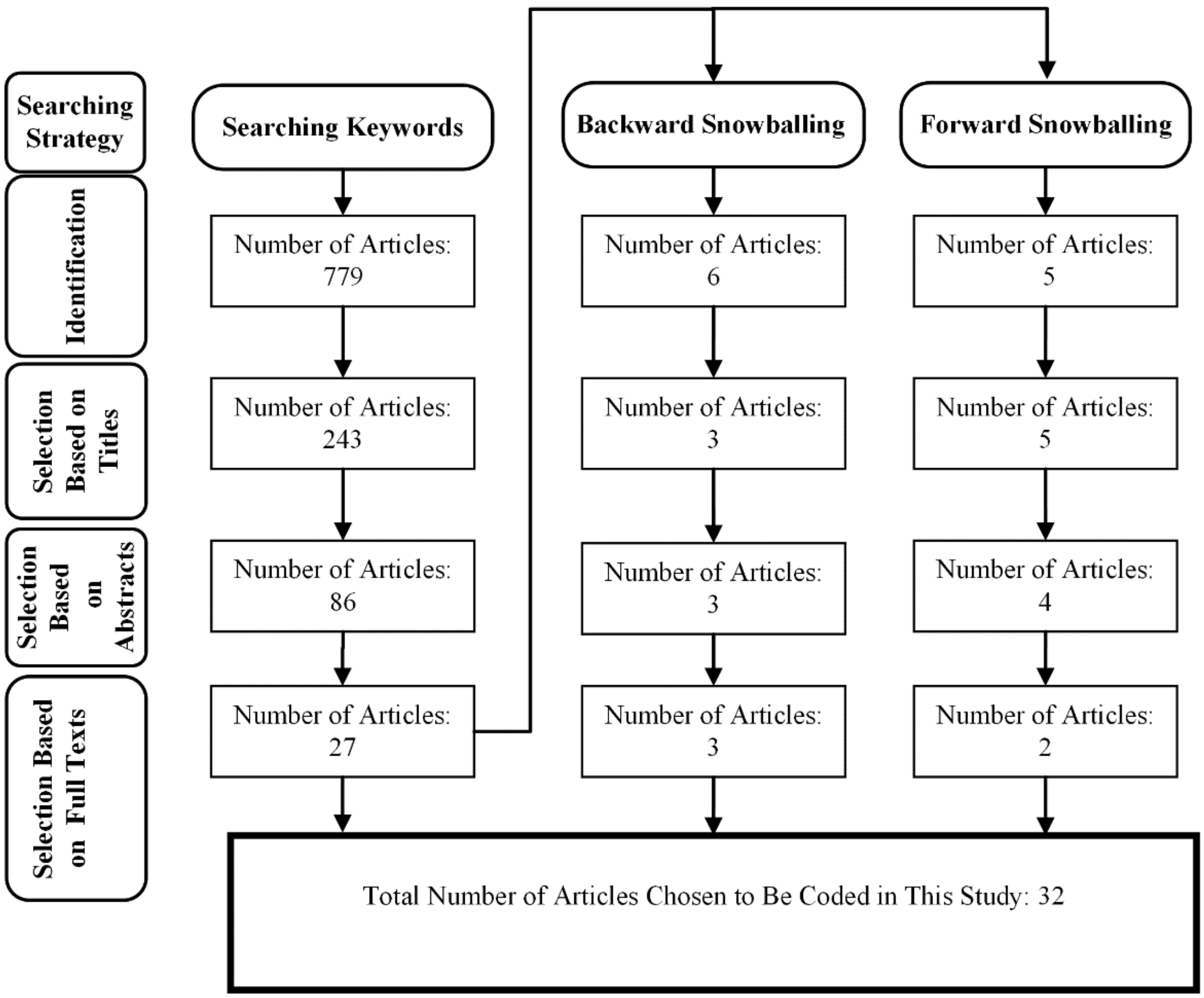

Figure 1. Number of Articles Extracted from Three Search Strategies

Our screening of articles was conducted through a multiple-step process. First, articles were selected based on their titles. If their titles were closely related to interventions and circuits education, they were chosen. Second, selected articles were screened by abstract reading. It was possible that their titles were assumed to be related to interventions in circuits education, but their approaches did not involve any interventions. Finally, articles were chosen by reading the paper completely. In sum, 32 papers were located for coding.

Coding of Studies

Our main objective was to find the interventions in circuits education and how they influenced undergraduate students in circuits courses, extracted information could be beneficial to determine which papers could be included in the study and which were not relevant or did not offer any interventions to students. The information was gathered from reading the title of the paper, the abstract, and the content with a particular focus on methods, discussions, and conclusions of the studies. In summary, our closed coding scheme was as follows: author(s) and publication year, whether they were used before, during, or after COVID-19, intervention category, intervention sub-category, teaching mode, duration of intervention, and research method. We also identified the number of participants in total, treatment, groups and control groups, and how effective the interventions were in changing student outcomes and performance.

Analyzing and Integrating the Outcomes of Studies

After the application of the inclusion and exclusion criteria came analyzing and integrating the outcomes of the studies. To start, a review of the research questions and the stated purpose of each study provided insight into the issues being addressed by each intervention and the context for their use. Then, based on the type of research methods, we determined which studies were using qualitative, quantitative, or mixed research methods approaches. When multiple control groups were available in a study, we selected the control group that was the most compatible with the treatment group except the treatment (e.g., [15]). Finally, study outcomes were extracted by examining the results, discussion, and conclusion sections of each article. Then, the answers to the article's research questions were identified, along with any discussion to further clarify those findings.

Synthesizing the Evidence

Most analysis and interpretation of data resulted from a comparison of grades for quantitative methods and synthesis of findings for qualitative methods. This involved grouping the studies by similarities in the intervention categories, subcategories, description, duration, teaching modes, research methods, and identifying their patterns.

IV. Results

The appendix contains the results of our review of 32 ASEE conference papers. As some papers collected contain more than one study, the total number of studies collected in this review was 44 out of 32 articles.

Classification Based on the COVID-19

A total of 31 studies were conducted before COVID-19 (e.g., [16]), 11 during COVID-19 (e.g., [17]), and only two studies after COVID-19 (e.g., [18]). It is worth mentioning that some studies did not mention COVID-19, but we considered that they were conducted during COVID-19 if studies took place from spring 2020 to summer 2022 because most of the universities had in-person classes in Fall 2022. Note that the U.S. Department of Health and Human Services designated the COVID-19 pandemic period between January 30th 2020 and May 11th, 2023 [19]. Table 2 shows a summary of the number of studies based on the COVID-19 period. Therefore, it can be concluded that most of the studies were conducted before the COVID-19 period. This is logical because the published years of conference papers are limited to 2014 to 2023.

Considering that the COVID-19 pandemic started in 2020, for the 6.5 years covered by our study, there were no papers published during the COVID-19 era. Consequently, only 2.5 years of the studies were conducted during the COVID-19 period, resulting in a smaller number of publications during this time.

Table 2. Number of Studies Based on the COVID-19 Period

COVID-19	Date Range	Number of Studies
Before	Before January 30th, 2020	31
During	Between January 30th, 2020 to August 23th 2022	11
After	After August 23th, 2022	2

Classification Based on the Class Modes

Based on the descriptions of studies, 19 studies were conducted on interventions for lectures and labs together (e.g., [16]), 10 intervention studies were conducted on only lectures (e.g., [20]), and 15 intervention studies were conducted exclusively on labs sections (e.g., [21]). Therefore, it can be concluded that while both labs and lectures offer unique interventions that enhance students' learning, many interventions are beneficial for both lab and lecture environments.

Classification Based on the Teaching Mode

Of the interventions identified, 29 were conducted in in-person classes (e.g., [18]), 11 in online (e.g., [22]), two in a combination of in-person and online, one in a combination of in-person and hybrid [23], and finally one with a combination of in-person, online and hybrid delivery methods [24]. One of the reasons for the high number of in-person interventions is that certain interventions required hands-on learning experience (e.g., [23]). Another reason is that before COVID-19, most of the classes were in-person therefore the interventions were conducted in these classes.

Classification Based on the Intervention Category

The types of interventions classified included 17 "Practice-Based/Research-Based Instructional Strategy (PBRBIS) Interventions," 26 "Learning Strategy Interventions," and one "Motivational Intervention." In other words, 57% of interventions were categorized as learning strategy interventions compared to 40% as practice-based/research-based instructional strategy (PBRBIS) interventions, and only 3 % were in the motivational category. Most of the interventions aim to improve students' cognitive and metacognitive since they are more aligned with curriculum objectives. Therefore, the number of interventions in "Learning Strategy Interventions" was higher compared to other categories of interventions.

Classification Based on the Intervention Sub-Category

The most popular sub-categories of interventions were "cognition," "flipped classrooms," and "management" with 9 studies for each one of them. Also, followed by eight for "technology enhancement learning" (e.g., [15]), six for "metacognition" (e.g., [25]) and there was one study for each of “inquiry-based learning” [26], “problem/case-based learning” [27], and “personal value” [28]. Regarding the PBRBIS interventions, 20% of studies used flipped classrooms as a sub-category of their intervention, two of which were conducted during COVID-19 in a time period when classes were in person. 20% of the interventions used cognition as new approaches to change or implement new learning strategies and 20% used the management sub-category by changing the environment or management of instructors.

Classification Based on the Intervention Duration

As shown in figure 2, the duration for most of the interventions is 15 weeks. The reason for this is that most of the interventions are conducted in fall semester or in spring semester. Since the duration for these semesters are 15-16 weeks in most of the universities, we used 15 weeks as an indicator that these interventions were conducted the whole semester. Also, it should be mentioned that for one paper which consisted of two studies, two semesters where chosen as the duration of the intervention therefore, we chose 31 weeks as the duration time [29].

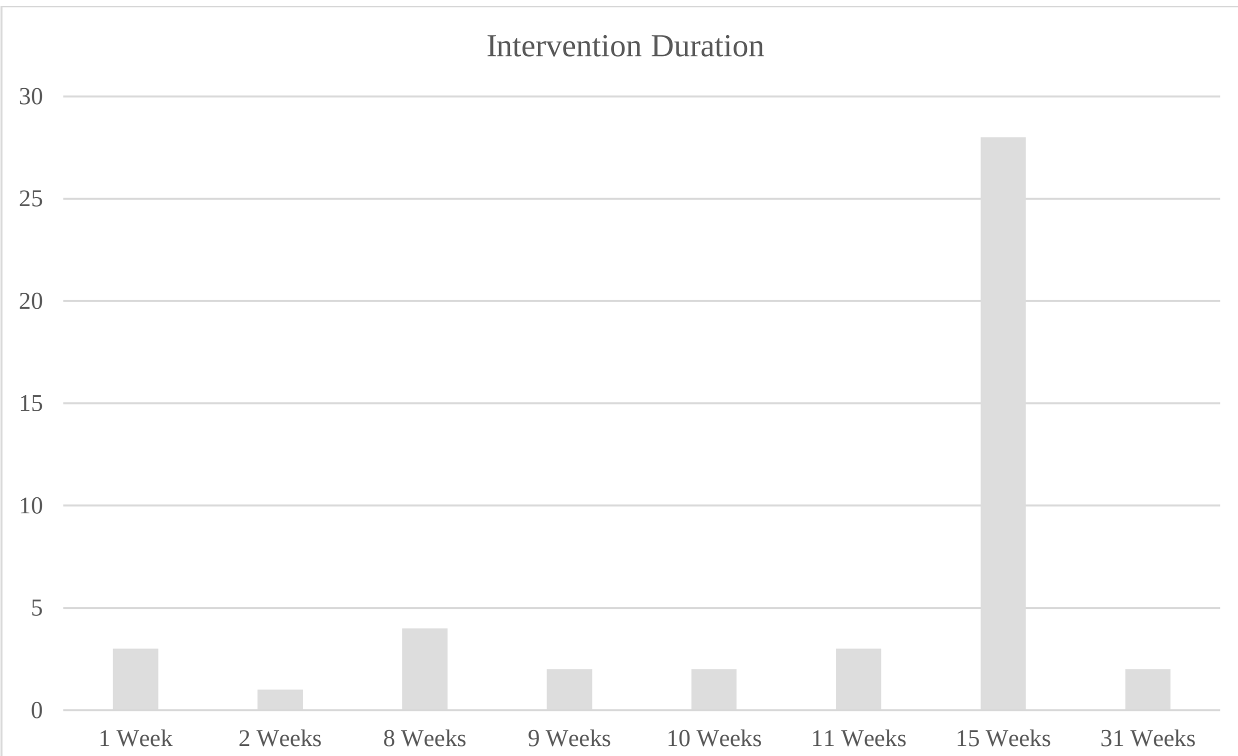

Figure 2. Classification Based on the Duration of Intervention

V. Discussion

We identified and reviewed 32 ASEE conference papers comprising of 44 studies on interventions in teaching circuits published over the last 10 years. Through this work, we addressed the following research questions, *What kind of interventions were conducted in circuits education and what impact did these interventions have on student performance?* and discussed findings based on the coding schemes.

Class Modes and COVID-19

We expect that the main reason for 69% of the interventions identified to be conducted for in-person classrooms compared to online and hybrid classrooms is the dates of the articles elected to study: 2014 to 2023. Since COVID-19 happened at the end of this period, most of the interventions were applied to in-person classrooms.

Trends in the Types of Intervention Categories and Sub-Categories

The trend for "Learning Strategy Interventions" was consistently the most utilized method of intervention from 2014 to 2019. However, after this period, due to the increase in "Technology Enhanced Learning" interventions, the trend for "PBRBIS" began to rise. Additionally, following the COVID-19 pandemic and the resumption of in-person classes, LSI interventions once again began to show an upward trend. Also, over the past 10 years, the majority of interventions published in the ASEE conference proceedings focused on improving and changing the learning strategies of students in circuits rather than improving the motivation of students to learn circuits. This can imply that instructors focused on improving students' learning in classes by introducing new pedagogies or interventions with more direct effects, rather than by increasing students' motivation such as their self-efficacy in learning circuits or sense of belonging in engineering. In other words, it is concluded that most of the focus was on "how to learn circuits better" not on "why you need to learn circuits."

From 2014 to 2016, metacognitive and cognitive interventions were not as popular, with most interventions being related to flipped classrooms and management strategies. During 2017 and 2018, interventions were mostly related to metacognition and flipped classrooms. However, after this period, from 2019 to 2020, the focus shifted to improving students' cognitive skills. In the last two years, from 2021 to 2023, there was a significant shift towards technology-enhanced learning, which is logical considering the efforts made to improve students' learning during the COVID-19 pandemic.

The most notable findings of this review relate to the categories and sub-categories of the intervention studies. Most of the interventions were counted as learning strategy interventions – novel interventions used to improve student performance in circuits or one of its component topics. According to the data and findings extracted from those studies, these interventions tend to be successful. The next most popular intervention categories were practice-based/research-based instructional strategy interventions. Consequently, there was not much overlap between the Learning Strategy and PBRBIS interventions. It was concluded that 94% of studies belonged in these first two groups of interventions, showing that most of the instructors insisted on improving the classroom environment, using new methods of teaching, and exploring new strategies for learning circuits content. The most popular intervention sub-categories were flipped classrooms and metacognitive interventions, each of which was rated 24% each between all the sub-categories.

Trends in the Intervention Durations and Research Methods

During 2014 and 2015, most of the interventions were used mixed method research, however from 2016 to 2023, most of the research method which was used was quantitative. Overall, 56% of total researches were quantitative. Qualitative research method had a consistent pattern from 2014 to 2023 except for 2016 and 2020 which the number of qualitative research method increased.

The reason that most frequent intervention periods were 15 weeks is that interventions were conducted in a typical fall semester or spring semester in the United States, which are about 15 weeks long with an additional week for exams. Also, other studies were conducted in the Summer, during workshops, or during two different semesters combined. The trend for the duration of interventions remained consistent throughout the entire 10-year period covered by these papers. This means that the duration of most interventions was 15 weeks and did not change significantly over time.

For 89% of the studies, the total number of participants was mentioned and only 62% further mentioned the number of students in a treatment group and control group which means these studies were more rigorously designed. Finally, only 17 studies showed a significant improvement in students' performance based on their text, which is 37% of all the studies which are included in our review.

Trends in Student Outcomes

Although most interventions were reported to be useful, in 8 out of 44 studies, the intervention did not result in the improvement of students' perception and performance (e.g., [30]), which accounts for 18% of the studies. Additionally, in 3 cases, despite not improving students' grades, the intervention resulted in positive effects on students' perceptions and motivations (e.g., [31]).

For 32 studies, which represents 75% of the total, the interventions were reported to have positive effects. Out of these, 16 studies, or 37%, reported an increase in students' grades, while 15 studies reported improvements in students' engagement and interest in in-class activities (e.g., [32]).

Limitations and Future Directions

While we tried to mitigate capturing all the intervention studies conducted on Circuits using multiple search tools and methods, there may be studies of interventions that we did not identify for inclusion. Also, in this review, we intentionally limited the scope of our search to studies published within the professional community of ASEE. However, many other publication venues could expand our pool of articles on Circuits interventions. In the future, we will be expanding beyond the scope of ASEE conference papers to collect new data and gain new insights on the studies and teaching of Circuits in engineering.

Conclusion

The finding of this review suggests that interventions in most cases had positive effects on students' performance and perception in circuits course which can be determined by students' final grades, project grades, surveys, DFW rates, and the number of enrollments for the course.

Despite these limitations and some of the interventions not having improvement on students' performance and perception, this review of the last decade of ASEE conference papers has found important impacts on circuits education for undergraduate students, which students, instructors, and universities can benefit from. Based on different circumstances, whether the intervention is applied to lectures, labs, or both, they can result in improvement of teamwork among students, their academic performance, their engagement with course material and in-class activities, motivation and confidence in facing challenging problems, conceptual knowledge of circuits, ability to transfer information to new settings, self-efficacy, students' satisfaction, and their quality of reports. Consequently, they can increase the number of students passing circuits course, the number of students receiving A's and B's, the number of students taking the circuits class for non-major students, students' grades for quizzes, finals, and projects, consistency of grades among different sessions, and encouragement for students to pursue electrical engineering majors. In summary, this systematic review highlighted the importance of using interventions in circuits classes understanding their effects on students' performance and perceptions in circuits course.

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Appendix

Table A. Summary of the 32 ASEE Conference Papers Utilized for the Systematic Review

Authors	#	Intervention Main	Intervention Sub	Tch. Mode	COVID-19	Duration (weeks)	Class Mode	Research Method	N_T	N_{TG}	N_{CG}	Outcomes
Al Weshah & Alamad (2021) [33]	1*	LSI	COG	P	Du	15	3	Quan	77	42	35	• Improved the teamwork experience of students • Improved academic performance of students in circuits analysis course
Alavi (2022) [17]	1	PBRBIS	FLP	P	Du	15	3	Quan	112	57	55	• Not Improved: DFW increased
	2	PBRBIS	FLP	O	Du	15	3	Quan	111	56	55	• Improved: DFW decreased • Increased students' engagement
	3	LSI	MNG	O	Du	15	3	Quan	104	49	55	• Not Improved: DFW increased
Aliyazicioglu & Dahlquist (2022) [15]	1	LSI	TEL	O	Du	15	2	Quan	63	30	33	• Improved course grade • Improved students' engagement
	2	LSI	TEL	O	Du	15	2	Quan	36	16	20	• Improved course grade • Improved students' engagement
Baghdadchi et al. (2019) [16]	1*	LSI	COG	P	Be	11	3	Quan	83	70	13	• Improved engagement in class activities • Improved engagement in course materials • Increased students' course grades
	2	LSI	COG	P	Be	11	3	Quan	41	28	13	• Improved engagement in class activities • Increased students' course grades
	3	LSI	COG	P	Be	11	3	Quan	24	11	13	• Improved engagement in course materials • Did not Increase students' course grades
Becker et al. (2023) [18]	1*	LSI	MCOG	P	Af	1	2	Quan	26	26	NR	• Improved motivation and confidence in understanding the problems • Improved conceptual knowledge of the study of circuits analysis • Student feedback regarding the writing exercises was positive
Becker & Plumb (2018) [26]	1*	PBRBIS	IC	P	Be	1	3	Quan	69	NR	NR	• Increased the conceptual understanding
Bell & Horowitz (2018) [28]	1*	MTV	PV	P	Be	9	3	Qual	NR	20	NR	• Increased the number of students taking this modified course
Berry (2015) [22]	1	LSI	COG	O	Be	10	3	Mixed	NR	NR	NR	• Decreased the performance for Summer 2013
	2	LSI	COG	O	Be	10	3	Mixed	NR	NR	NR	• Increased scores by 10% with the second offering

Cheney et al.(2019) [20]	1	PBRBIS	FLP	P	Be	15	1	Mixed	210	123	87	• Reduced stress • Increased enjoyment • Improved engagement • Increased project grades
Chin et al. (2019) [31]	1	LSI	COG	P	Be	1	1	Mixed	127	55	72	• Did not result in statistically significant improvement for student performance • Resulted in positive motivation
Claussen & Dave (2017) [34]	1	LSI	MCOG	P	Be	15	1	Quan	57	27	30	• Failed to show a significant increase in improvement score
	2	LSI	MCOG	P	Be	15	1	Quan	51	22	29	• Failed to show a significant increase in improvement score
Connor et al. (2016) [23]	1	PBRBIS	TEL	P & H	Be	15	3	Qual	271	NR	NR	• Students made significant gains in course-specific content knowledge. • Improved the ability to transfer information to a new setting • Improved students' problem-solving ability
Cooney et al. (2017) [27]	1*	PBRBIS	PCBL	P	Be	15	3	Quan	44	22	22	• Significantly decreased errors in the intervention lab section • Increased the students' understanding of circuits and their building
Cosoroaba (2020) [32]	1*	LSI	COG	P	Be	15	2	Qual	23	NR	NR	• Increased students' engagement. • Enhanced the quality of reports by instructors • Increased the consistency of grades compared to previous years
Das et al. (2022) [21]	1*	LSI	MCOG	P	Du	15	2	Quan	154	86	68	• Reduced students' frustration • Reduced "how-to" questions during the lab sessions • Improved simulation skills by using LTspice • More pleasant lab experience by students was noticed.
Ferri et al. (2014) [35]	1*	LSI	MNG	O	Be	8	3	Quan	286	NR	NR	• Made the outcomes more consistent from different sessions
Freeborn et al. (2020) [36]	1	LSI	MNG	P	Be	8	1	Qual	23	NR	NR	• Increased in confidence
Freeborn (2022) [37]	1	LSI	MCOG	P & O	Du	8	1	Qual	49	NR	NR	• Improved students' performance in the course • Students had a positive experience
Fritz et al. (2021) [38]	1	PBRBIS	TEL	O	Du	2	1	Quan	100	50	50	• Improved performance
Kaleem et al. (2016) [24]	1*	PBRBIS	FLP	P & O & H	Be	15	3	Qual	153	32	121	• Reduced confidence in flipped classrooms compared to hybrid and traditional classes

												• Students expressed favorable opinions toward hybrid and traditional compared to flipped classrooms
Kaur & Swift (2020) [30]	1	LSI	COG	P	Be	15	2	Qual	NR	NR	NR	Perspective of TAs: • Manuals lacked clear instructions Perspective of students: • Unclear data usage instructions • Dissatisfaction with lab assignments
Lawson & Kouo (2021) [39]	1	PBRBIS	TEL	O	Du	8	2	Qual	44	28	16	• Reduced students' satisfaction levels for online lab compared to on-site lab
Lin & Sandelin (2020) [29]	1	LSI	MNG	P	Be	31	3	Mixed	17	NR	NR	• Gave students the opportunity to apply knowledge and skills from two different courses taken in the same quarter to design practical circuits • Encouraged students to pursue electrical engineering majors.
	2	LSI	MNG	P	Be	31	3	Mixed	31	NR	NR	• Gave students the opportunity to apply knowledge and skills from two different courses taken in the same quarter to design practical circuits • Encouraged students to pursue electrical engineering majors.
O'Brien et al. (2015) [25]	1*	LSI	MCOG	P	Be	15	2	Qual	150	75	75	• Increased the average for students who played the game scored by11% compared to non-player stucents
Rockland et al. (2016) [40]	1	PBRBIS	FLP	P	Be	15	3	Qual	NR	NR	NR	• Increased the final average of class compared to previous year by 6%
Saleheen et at. (2015) [41]	1*	LSI	MNG	O	Be	15	2	Mixed	34	16	18	• Significantly increased the grades between the pre-test and post-test
Saleheen et al. (2016) [42]	1	PBRBIS	TEL	O	Be	15	2	Quan	28	18	10	• Increased levels of engagement • Improved test scores
Sanchez et al. (2016) [43]	1*	LSI	MNG	P	Be	15	1	Quan	34	9	25	• Improved students' ability to represent the circuit at the beginning of the optimization process at a basic level • Did not improve students' ability to represent mathematical model as well as the computational model • Did not improve students' ability to provide an acceptable conceptual explanation of the optimized circuit.
	2*	LSI	MNG	P	Be	15	1	Quan	26	13	13	
	3*	LSI	MNG	P	Be	15	1	Quan	32	15	17	
Schurgers et al. (2023) [44]	1	PBRBIS	TEL	P	Af	15	3	Mixed	60	32	28	• Increased self-efficacy • Made achievements more scalable

												• Aimed for at-risk students
Sullivan-Green (2018) [45]	1*	PBRBIS	FLP	P	Be	15	1	Quan	121	35	86	• Increased percentage of students passing the course • Having higher achievement at all grade levels
	2*	PBRBIS	FLP	P	Be	15	1	Quan	123	32	91	• Increased the number of students passing the course from 87.2% in traditional course to 93.8%
	3*	PBRBIS	FLP	P	Be	15	1	Quan	236	157	79	• Increased the number of students who received A's and B's by 10%
Swift & Wilkins (2014) [46]	1	PBRBIS	FLP	P	Be	15	1	Qual	21	NR	NR	• Resulted in a high level of students' satisfaction
Yan et al. (2021) [47]	1	PBRBIS	TEL	P & O	Du	15	2	Mixed	52	NR	NR	• Didn't change the grades for for the treatment group compared to the control

Note. * Indicates that the study reported significant findings. Af = After; Be = Before; Class Mode: 1 = Lecture, 2 = Lab, 3 = Lecture & Lab; COG = Cognitive; CPP = Cal Poly Pomona; CSULA = California State University, Los Angeles; Du = During; FLP = Flipped classrooms; IL = Inquiry-based learning; LSI = Learning Strategy Interventions; MCOG = Metacognitive; Mix = Mixed Method; MNG = Management; MTV = Motivational Intervention; N_{CG} = Number of Participants in Control Group; N_T = Total Number of Participants; N_{TG} = Number of Participants in treatment Group; NR: Not Reported; PCBL = Problem/case-based learning; PBRBIS = Practice-Based/Research-Based Instructional Strategy; PV = Personal Value; Quan = Quantitative; Qualitative = Qual; SJSU = San Jose State University; Tch. Mode = teaching mode: P = In-person, O = Online, H = Hybrid; TEL = Technology-Enhanced Learning