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Interventions in Circuit Education in K-12 Worldwide: A Systematic Review

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Abstract

Understanding introductory circuit concepts would be beneficial for K-12 students pursuing related majors in college. Accordingly, various educational interventions have been designed and implemented for students at the K-12 level. Previous reviews of circuit interventions were limited to the undergraduate population, outdated, or did not identify intervention types. Therefore, we investigated (a) what types of interventions were conducted in circuit education at the K-12 level around the world from 2000 to 2025? (b) what impact these interventions had on students, and (c) what similarities and differences exist in these interventions across countries. We conducted a systematic review by searching and filtering studies published from 2000 to 2025. Specific keyword searches and forward and backward snowballing were used to locate 23 papers, including 38 studies. Due to our defined eligibility criteria, such as publication in English, 43% of the papers reporting interventions included in this study were administered in the United States. Among categories of interventions, motivational interventions were the least common, and regarding learning strategies, cognitive-focused interventions outnumbered metacognitive and management strategies. Interventions at the high school level were mainly designed to have effects on student perceptions, as preparations for engineering majors align more with high school curricula. Hence, there were generally more interventions at this level to shape perceptions of electrical engineering. High school curricula also covered more advanced topics, offering instructors greater flexibility in designing interventions and necessitating strategies to address these challenging subjects.

Keywords: Circuits, Interventions, Elementary, Middle School, High School, Pre-College

1. Introduction

Developing new teaching methods is essential to effectively impart knowledge, spark students' interest, and encourage further exploration. This is especially true in science and engineering education, where complex concepts often need thoughtful teaching methods to help students understand and stay engaged. One area where such interventions are particularly important is circuits education. Almost all modern devices and systems, such as those used in communication, computing, or power delivery, are built using circuit elements that have grown increasingly complex over time. Electrical circuits form the basis for designing, optimizing, and sustaining a wide range of electronic systems. According to the U.S. Bureau of Labor Statistics, the demand for electrical and electronics engineers is expected to increase by 9% from 2023 to 2033 [1]. In response to this growing need for electrical and computer engineering, educators have increasingly emphasized introducing circuit-related concepts as early as the K-12 level [2].

Over the past 25 years, several reviews have examined circuits education interventions to better understand and track instructional approaches and their impacts on students [3]-[5]. While some reviews focused primarily on undergraduate populations [3]-[4], they did not comprehensively categorize different types of interventions used [5]. In addition, a significant gap remains in the literature regarding pre-college populations, where distinct instructional interventions have been implemented but not systematically examined (e.g., [6]). Classifying interventions by instructional type helps identify effective teaching strategies and supports evidence-based decision-making by educators and policymakers in K-12 education. To address this gap, this study conducts a systematic review of 23 papers published over the past 25 years that focus on circuits education interventions for K-12 students. Several papers reported multiple intervention studies (e.g., [7]), resulting in a total of 38 studies analyzed.

1.1 Objectives of the Review

The primary goal of this paper is to systematically review interventions in circuits education at the K-12 level, categorize them, and synthesize findings from existing studies. This paper addresses the following research questions: (a) What types of interventions have been carried out for K-12 students learning about circuits from 2000 to 2025?; (b) What impact did these interventions have on students?; and (c) What similarities and differences exist in these interventions?

2. Literature Review

2.1 Typology of Interventions

According to the APA dictionary, in a research design, an intervention refers to an experimental manipulation intended to assess the effect of changing one or more independent variables on a single dependent variable [8]. In general, an intervention is a planned, organized, and usually time-limited strategy designed to change a process or outcome for a student or group of students [9]. In educational research, interventions may vary widely in instructional approach, primary focus, level of structure, and mode of implementation. Such interventions are commonly used to enhance students' learning outcomes, engagement, and conceptual understanding. To better understand how these interventions are structured and applied in educational research for students, several scholars have proposed classification frameworks.

Referring to the classifications proposed by [9]-[11], this paper categorizes interventions into three major types: (a) motivational interventions, (b) learning strategies interventions, and (c) practice- or research-based instructional strategies. Motivational interventions usually aim to improve student engagement and self-efficacy. [9] further divides this category into several subcategories, such as (a) task value, (b) framing, (c) personal value interventions, (d) mitigating stereotype threat, and (e) changing attributions. Another major category, learning strategy interventions, focuses on teaching purposeful techniques to students, such as organization, elaboration, and monitoring, which help them learn more effectively. This is further divided into three sub-categories: (a) cognitive strategies, (b) metacognitive strategies, and (c) management strategies [10].

The third important classification, Practice-Based/Research-Based Instructional Strategy (RBIS), refers to instructional approaches that have been proven through research to enhance student learning outcomes. It is further divided into sub-categories as follows: (a) conceptual changed strategies, (b) cooperative learning, (c) discovery learning, (d) inquiry-based learning, (e) peer-led instruction, and (f) problem-based learning [11]. Table 1 presents the intervention categories, sub-categories, and examples for each one.

Table 1. Classification of Interventions Based on Categories and Sub-Categories

Categories	Sub-Categories	Examples	Reference
Motivational Interventions [9]	Task Value	Utility-Value, Communal Utility-Value, Parent Utility-Value	[9]
	Framing	Attributional Reframing, Mindset, Self-Efficacy, Social Belonging	[12]
	Personal Value	Values Affirmation	[13]
Learning Strategy Interventions [10]	Cognitive Strategies	Elaboration, Organization, Rehearsal	[14]
	Metacognitive Strategies	Self-Planning, Self-Monitoring, Self-Evaluating	[15]
	Management Strategies	Management of Effort (Self-Regulation), Peer/Teacher, and Environment	[16]
Research Based/ Practice Based Instructional Strategy (RBIS) [11]	Conceptual Changed	Cognitive Conflict	[17]
	Cooperative/ Collaborative	Team Structured, Group Collaboration	[18]
	Discovery Learning	Guided Experiments, Testing Hypothesis	[19]
	Flipped Classrooms	Pre-class Videos and Modules	[20]
	Inquiry-based Learning	Question-driven Investigations	[21]
	Peer-led instruction	Peer Instruction, Teaching Assistants	[22]
	Problem-based Learning	Projects, Real-world Difficulties	[23]

2.2 Interventions in Circuits Education in K-12

Teaching electric circuits is widely recognized as a persistent and challenging conceptual issue due to students' difficulties in forming accurate mental models and overcoming common misconceptions [24]-[25]. Additionally, the K-12 level is a crucial window for circuits education, as students at this level are actively developing foundational scientific reasoning skills and forming their attitudes toward STEM disciplines. Introducing circuit concepts early helps prevent misconceptions and supports the growth of systems-thinking abilities [26]-[27]. Therefore, a variety of interventions have been developed to improve the conceptual accessibility and engagement of circuits. These interventions range from inquiry-based curricula and hands-on kits to virtual and graphical simulations. Utilizing the Squishy Circuits is an example of a hands-on learning intervention that engages young learners through tangible materials to explore conductivity and circuit components [28]. Similarly, using virtual platforms such as the PhET Circuits Construction Kit allows safe visualization and experimentation of electrical current [29].

Notably, circuits interventions for K-12 are often studied in isolation, without being systematically classified or compared within a comprehensive framework. In addition, while K-12 STEM education is well-studied, systematic reviews of circuit-specific instructional interventions remain limited. Much of the existing circuit education literature has emphasized undergraduate populations, resulting in a gap in understanding how best to support younger learners [3]-[4]. Consequently, there is a clear need for a systematic review that identifies, categorizes, and synthesizes the range of intervention types used in K-12 circuits education. Such a review would clarify how different instructional strategies support conceptual understanding of circuits and inform the development of more coherent and effective teaching practices at this critical stage.

3. Method

To ensure transparency and reproducibility of this review, a systematic approach was utilized based on accepted synthesis principles. Building on foundational steps for conducting systematic reviews by [30] and specific protocols for selection and synthesis phase by Cochrane's handbook [31], the systematic review process was conducted through a framework with the following phases: (a) defining the eligibility criteria, (b) implementing searching strategies and screening process for the literature, (c) extracting and categorizing the data based on defined coding themes, (d) synthesizing findings and (e) interpreting the evidence.

3.1 Defining the Eligibility Criteria

The first stage involved developing the study questions and setting inclusion and exclusion criteria. These criteria defined the standards a study had to meet to be considered relevant within the context of this review. For a study to be included in this systematic review, it had to meet all the following four criteria: (a) Primary Focus: The study must have a specific educational intervention, teaching strategy, or pedagogical approach aimed at teaching concepts of electric circuits; (b) Target Population: The study population must involve students at K-12 grade levels. Studies that involved only graduate or undergraduate students were ineligible; (c) Publication Timeframe: Studies published between January 1, 2000 and December 31, 2025 were included in the review; and (d) Publication Language: Studies must be available in English, regardless of country of origin.

3.2 Searching Strategies and Screening Process for the Literature

The initial Google Scholar search yielded a large number of results, many of which were irrelevant to our study. We then refined our keyword searches, yet the volume and irrelevance of some studies persisted. To better target circuit interventions, we focused our search on several well-known journals and conferences in STEM education, such as Journal of Engineering Education (JEE), Journal of Research in Science Teaching (JRST), Institute of Electrical and Electronics Engineers (IEEE), and American Society for Engineering Education (ASEE). IEEE was included because circuit education falls under electrical engineering, while ASEE was chosen to capture relevant conference papers alongside journal articles. Search keywords used for locating articles from ASEE, IEEE, JEE, and JRST are summarized in Table 2.

Table 2. Keywords and Search Results from Popular Journals and Conferences

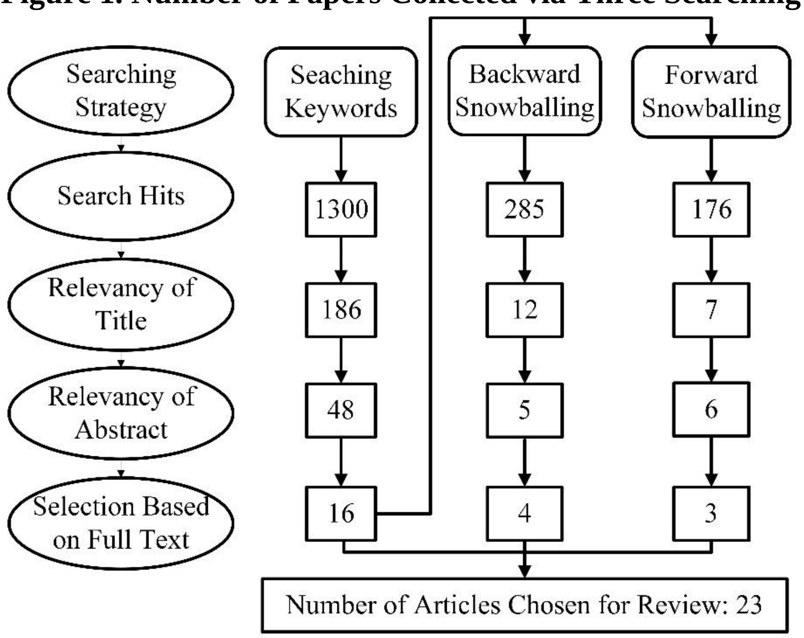
Keywords Used	ASEE	IEEE	JEE	JRST
"circuits"	8,976	459,548	57	75
"circuits" AND "intervention"	932	1,090	14	43
"circuits" AND "teaching" AND "intervention"	864	17	13	43
"circuits" AND "intervention" AND "high school"	642	184	13	12
"circuits" AND "intervention" AND "middle school"	266	6	5	10
"circuits" AND "intervention" AND "elementary"	145	7	2	7

Note. ASEE = American Society for Engineering Education; IEEE = Institute of Electrical and Electronics Engineers; JEE = Journal of Engineering Education; JRST = Journal of Research in Science Teaching

However, this approach excluded a considerable number of relevant studies, particularly international research and articles published in less widely indexed journals. To address this, we expanded our search by accessing additional academic databases available through the university libraries, including ERIC (via EBSCOhost), ProQuest Research Library, Scopus (Elsevier), and Wiley Online Library. Additionally, we used AI tools, such as ChatGPT, to discover further relevant journals and publications, introducing us to sources, such as the International Journal of Science Education, EURASIA Journal of Mathematics, Science and Technology Education, and many more. Selected articles were used to identify further relevant papers using the forward and backward snowballing strategy as defined by [32]. The snowballing procedure was iteratively repeated until no further relevant articles could be found.

After creating the initial pool from the identified articles collection, papers deemed relevant to educational interventions were selected through a preliminary title-based screening. The number of papers was further narrowed by reviewing the abstracts in a second round of screening. Lastly, a detailed full-text review was conducted to ensure that the most relevant intervention-based studies meeting the inclusion criteria were selected. Figure 1 presents how articles were identified using each strategy and the process of selecting 23 articles for inclusion in this study.

Figure 1. Number of Papers Collected via Three Searching Strategies



3.3 Extracting and Categorizing the Data Based on the Defined Coding Themes

Data extraction was conducted by two researchers and recorded in Microsoft Excel. A second-year undergraduate student majoring in Electrical Engineering reviewed each paper and extracted the relevant information for coding. The extracted data were then cross-checked by a Ph.D. student in Engineering Education with an Electrical Engineering background. An assistant professor in Engineering Education guided each step of the systematic review and supervised the whole process to ensure the consistency of coding.

In the case that the articles included two or more intervention studies (e.g., [7]), specific study IDs were created for each study, and each study was coded separately. Overall, in the 23 extracted articles, we identified 38 studies reviewed in this paper. In summary, our coding included the following information about the papers: author(s) and publication year, country of origin, intervention, number and education level of the participants, research design, assessment tools, intervention category and subcategory, and findings.

3.4 Synthesizing Findings and Interpreting the Evidence

Using the predefined coding scheme, we synthesized interventions from all studies to address the research questions and identify patterns in K-12 circuits education. Intervention characteristics and outcomes were systematically examined by reviewing the results, discussion, and conclusion sections of each article. This process allowed us to determine how each intervention influenced students' learning, engagement, and performance, and to ensure that reported effects were interpreted within the context of each study's design and implementation. We grouped interventions into categories and subcategories to enable cross-study analysis that allowed consistent comparison of instructional approaches, modes of implementation, and the outcomes. Both quantitative evidence, such as pre- and post-test results and performance measures, and qualitative evidence, including observations of student engagement and conceptual understanding, were considered in the synthesis.

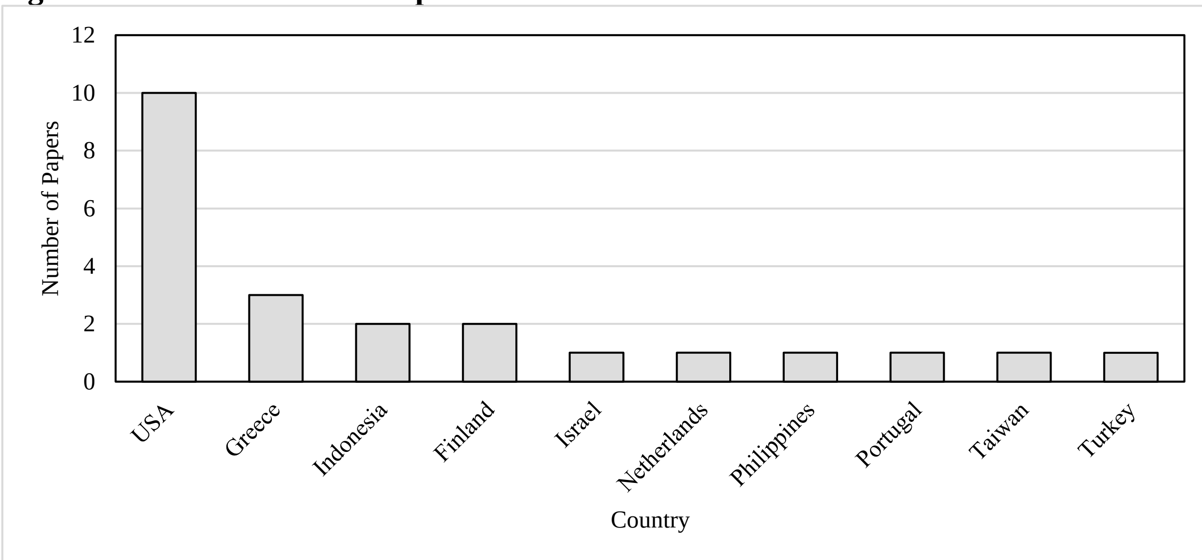
The integration of these findings enabled us to identify dominant intervention trends and recurring instructional patterns. Based on this synthesis, research questions were addressed, and interpretations were developed to clarify how different types of interventions existed within K-12 circuits education. This combined analytical approach strengthened the data extraction, categorization, and interpretation, providing a comprehensive understanding of how instructional strategies support learning in electric circuits.

4. Results

4.1 Demographic and Publication Overview

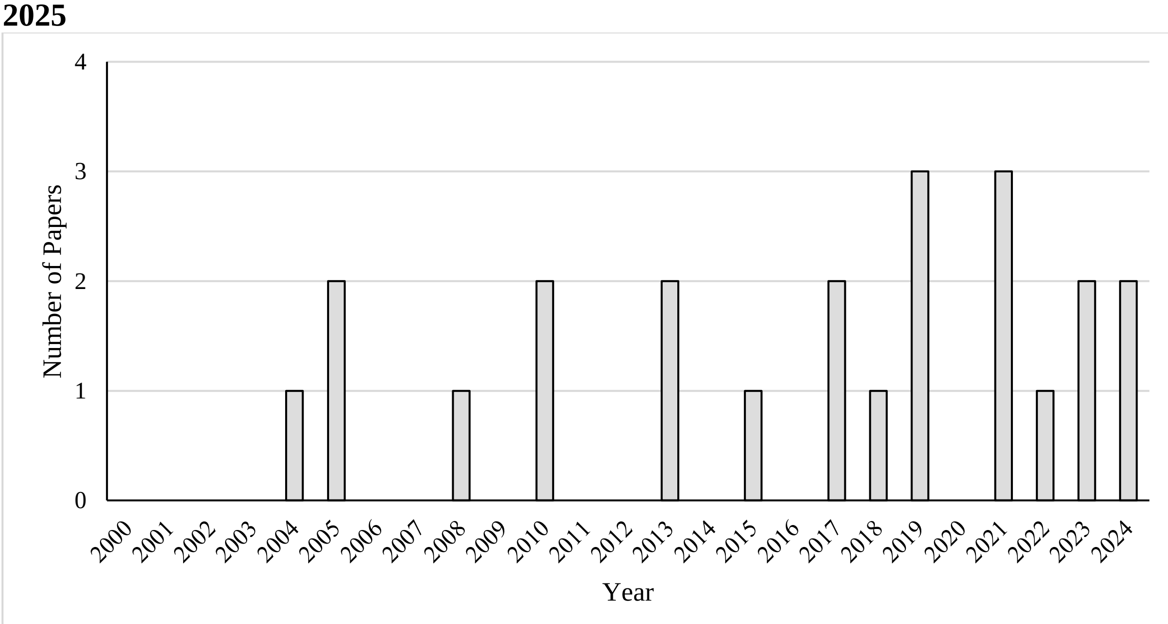
Table A1 in the appendix presents the results of our review of 23 papers that include a total of 38 studies. Figure 2 illustrates the countries in which the interventions were conducted. Accordingly, most studies were conducted in the United States, with 10 papers, followed by Greece, Indonesia, and Finland with 3, 2, and 2 papers, respectively. Other represented countries include Israel, the Netherlands, the Philippines, Portugal, Taiwan, and Turkey, each contributing one paper.

Figure 2. Distribution of 23 Papers Across 10 Countries Included in the Review



Participants' educational levels varied across the articles: 8 papers focused on PreK to elementary school students, 5 on middle school students, and 8 on high school students. Two papers focused in more than one levels: middle school & high school [33] and elementary school & high school students [34]. Reported sample sizes across studies showed wide variability, ranging from as few as 7 participants [35] to as many as 2,880 in a single study [36]. Figure 3 presents the distribution of the reviewed publications across time. Specifically, 17.4% of the studies were published in the 2000s, 47.8% in the 2010s, and 34.8% between 2020 and 2025. Most of these papers (82.6%) were journal articles, while conference papers made up 17.4%. The most frequently represented journals were Journal of Research in Science Teaching (JRST) and Journal of Science Education and Technology (JSET), each featuring four papers.

Figure 3. Distribution of Included Studies Across 26 Years of Publication from 2000 to 2025



4.2 Study Designs and Assessment Frameworks

Regarding research design, seven articles employed quantitative approaches, three utilized qualitative approaches, and thirteen adopted mixed methods research design. . The most prevalent intervention involved the use of various circuit kits, appearing in seven studies. Reviewed interventions ranged from curriculum-based implementations (e.g., [37]) to technology-driven approaches, such as microcontrollers [33] and Arduino platforms [38]. In addition, a number of studies also integrated simulation tools and emerging technologies, notably Internet of Things (IoT) applications (e.g., [39]), at the high school level.

For assessment strategies, a variety of tools were employed, including pre- and post-tests, classroom discussions, and interviews. Certain studies utilized specialized instruments, such as the Word Association Test (WAT) [37] and concept inventory assessments (e.g., [40]), to evaluate student performance. Overall, the most frequently used method involved administering pre- and post-tests to evaluate changes in students' learning and understanding of circuits concepts.

4.3 Intervention Characteristics and Outcomes

Table 3 delineates the distribution of interventions across various categories and subcategories, with 42.1% of the studies employing research-based or practice-based instructional approaches. The remaining studies were distributed between learning strategy interventions and motivational interventions, accounting for 39.5% and 18.4%, respectively. Regarding study outcomes, among the 23 interventions analyzed, only 3 reported no effects. All other studies demonstrated positive results. The majority of the studies primarily focused on student performance outcomes (52.6%), while a considerable proportion examined student perceptions and related parameters, including motivation (15.8%), creativity (13.16%), cognitive structures (10.5%), and problem-solving skills (10.5%). Notably, interventions targeting creativity and other affective or cognitive parameters uniformly yielded positive outcomes. Conversely, 21.1% of the studies assessing performance failed to identify statistically significant improvements.

Table 3. Classification of Interventions by Category and Sub-category

Categories	Sub-Categories	Studies		
		n	%	
Motivational Interventions	Task Value	2	5.3	18.4
	Framing	2	5.3	
	Personal Value	3	7.9	
Learning Strategies Interventions	Cognitive Strategies	11	28.9	39.5
	Metacognitive Strategies	3	7.9	
	Management Strategies	1	2.6	
Research Based/Practice Based Instructional Strategy Intervention	Conceptual Changed	5	13.2	42.1
	Discovery Learning	8	21.1	
	Flipped Classrooms	0	0.0	
	Inquiry based Learning	1	2.6	
	Peer led instruction	0	0.0	
	Problem-based Learning	0	0.0	

	Cooperative/Collaborative	2	5.3	
Total		38	100.0	100.0

5. Discussion

5.1 Demographic and Design Trend

Because our inclusion criteria were limited to studies published in English, it is very likely that many valuable interventions reported in other languages were missed. Instructional strategies for teaching circuits are probably being developed all around the world, but they remain underrepresented in the international literature. In another word, the geographic distribution of the included studies is heavily skewed towards the United States. As a result, the findings should be interpreted with caution when discussing global trends in circuit-based interventions. In addition, since popular American journals were our main starting point for identifying studies, a large proportion of the reviewed articles came from the United States. From the studies that were included, most interventions were conducted at the high school level. This pattern makes sense because high school can become an important stage [41] where students can build a foundation before entering college, while also being cognitively ready to grasp more complex electrical concepts as compared to middle school or elementary school students.

The wide variation in sample sizes across studies highlights the flexibility of circuit education interventions. Some studies focused on small-scale classroom implementations, while others demonstrated large-scale impact, such as curriculum reforms implemented across as many as 152 schools in three U.S. states [36]. This shows that effective interventions can be designed and implemented at both micro and macro levels. Also, a clear upward trend in publications on circuit education interventions is evident from Figure 3. While 11 studies were included from the 2010s, 8 studies have already appeared in just the first half of the 2020s, which strongly reflects the growing importance and research interest in circuits education. Finally, as noted by [3], the period following COVID-19 appears to have influenced this growth. Findings from Figure 3 suggest a noticeable increase in publications after the pandemic, possibly due to increased internet accessibility and the widespread adoption of virtual modalities that became normalized during and after lockdown.

Among the reviewed studies, mixed methods research design is the most popular. More than half of the papers combined quantitative tests with qualitative assessment, giving us a better idea of the effects of interventions. Circuit kits are commonly used, especially at the elementary and middle school levels as they provide hands-on, tangible learning experiences. However, many commercially available kits and technology-based tools require financial investment, which can limit their accessibility in schools with limited resources. To address this gap, initiatives like those by [42] in Turkey have focused on developing affordable, low-cost kits that make hands-on learning more accessible.

5.2 Intervention Characteristics and Outcomes

Among categories of interventions, motivational interventions were the least common, as shown in Table 3. This scarcity may stem from the misconception that K-12 students are too young to develop a genuine interest in circuits or electrical engineering. However, interventions can be done with students as early as pre-school to attract their interests in circuits. Regarding learning strategies, cognitive-focused interventions outnumber metacognitive and management strategies. This pattern suggests that many interventions prioritize introducing core concepts and stimulating initial cognitive engagement in K-12 students rather than promoting students' self-regulated learning skills, which may develop later in their academic journey. Finally, the high proportion of cognitive interventions is not surprising. Additionally, students tend to be naturally drawn to interactive gadgets and tools, which can make learning more enjoyable and effective.

Most interventions focused on performance outcomes, reflecting the traditional emphasis on measurable academic achievement when evaluating educational effectiveness. However, improvements in test scores are not always guaranteed, as 21.1% of studies reported no statistically significant gains. This suggests that performance scores alone may not fully capture the breadth of students' learning and development. Instead, it raises a concern: could an overemphasis on performance testing unintentionally limit students' creativity or motivation? Although this idea is not yet strongly supported by empirical evidence, it points to the potential value of balancing performance measures with greater attention to creativity, engagement, and motivation in evaluating the effectiveness of educational interventions. The promising positive effects of interventions support the value of using intervention-based approaches in this area of circuits education.

5.3 Implications for Practice

Our findings indicate that classroom activities involving hands-on manipulation of components and experimentation, such as utilizing various circuit kits, Arduino microcontrollers, E-textiles toolkits, and FPGA boards, facilitate a more effective construction of conceptual understanding among students. Nevertheless, a more comprehensive comparison among the available physical tools, their impact on student learning, and their overall application within K-12 education is needed.

Educators are encouraged to perceive interventions not solely as assessment-driven instructional tools aimed at enhancing student performance but also as opportunities to increase engagement among young learners, particularly those encountering circuitry for the first time in K-12 settings. Consequently, integrating circuit-related interventions in K-12 education may significantly influence students' decisions to pursue electrical engineering as a future academic discipline.

5.4 Limitations and Future Direction

Despite the insights this review provides in K-12 circuits education, there are certain limitations. The fact that only those studies written in English were eligible for the review made it linguistically biased, because some effective interventions worldwide may not have been reviewed because either they were never documented or were in other languages. Differences in the research designs, encompassing subjects, grade levels, and interventions in these studies also made studies not directly comparable each other. It is also important to have more research in K-

12 circuits education in the future, as well as appropriate assessment tools to measure the impact on student outcomes.

It is important to acknowledge that the term "K-12" used in this study may not be universally applicable across different national education systems. Historically, K-12 education has been characterized as comprising primary or elementary education and lower secondary education. By the early 21st century, these terms had increasingly been replaced by the concept of "basic education" [43]. However, because we were unable to find recent reports and updates on this topic, we have used K-12 education for the education period from the start of elementary schooling through the final year of high school.

5.5 Conclusion

This systematic review examined the effects and trends of instructional interventions in circuits education and found that 78.9% of the studies reported positive impacts on students' learning or on other measured parameters in K-12. This high success rate shows that well-designed interventions can effectively support students' understanding of circuits. At the same time, the trends observed in the literature indicated that classrooms were continuously adapting to rapid technological progress. While this direction is promising, greater attention should also be given to developing and implementing motivational interventions to foster students' interest and engagement for sustained learning. Across different countries, interventions continued to be implemented and refined, demonstrating a global effort to improve K-12 circuits education.

One of the key contributions of this review is the organization of a wide range of intervention approaches into clear categories and subcategories, making it easier to identify patterns in instructional strategies within K-12 circuits education. Therefore, this review provides practical guidance for teachers, curriculum designers, and researchers who aim to select or design effective circuit curricula. Furthermore, it highlights the need for future studies to expand the number of interventions, make greater use of mixed methods designs to explain both how and why the intervention affected students' perceptions and performance, and explore long-term learning outcomes. Focusing on these interventions will facilitate more efficient and impactful circuits education.

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Appendix

Table A1. Summary of Papers Used in the Study

Authors	#	N_T	N_{CG}	N_{TG}	SL	Country	RM	Assessment	Study Objective	Controlled Approach	Intervention	Category		Findings
												Main	Sub	
Aydeniz [40]		99	49	50	ES	USA	Mixed	Circuits Concept Inventory Test and Classroom Observations	Learning about Electricity and Circuits	Reading text, Lectures, Hands on activity using a battery and a bulb	Circuits KitBook	LSI	CS	Treatment group significantly outperformed the Control group
Baptista et al. [37]		638	317	321	HS	Portugal	Quan	Word Association Test (WAT)	Change in Cognitive Structures after Learning Sequence about Circuits	Teacher-centered approach in teaching circuits	Student-centered STEM approach in teaching circuits	RBIS	CCS	↑ Development of treatment group's cognitive structures on topic of Circuits
Bicer et al. [33]		86	0	86	MS & HS	USA	Mixed	Pre-Post online Survey using Likert scale, Interviews, Observations	Interest in pursuing a career in engineering and self-perception about creativity, Problem solving	-	Arduino based Microcontroller	MI	TVI	↑ Improved students' self-perception of creativity ↑ Problem-solving ↑ Engineering interest
Bucayong et al. [6]		268	28	240	HS	Philippines	Quan	Pre- and Post-Tests, DIRECT Instrument	Conceptual understanding of circuits	Traditional Teaching	Whole Brain Strategy	RBIS	IBL	↑ Learning gain in DC Circuits Experimental group had greater gains than control group
Cevik, & Cerit [42]		NR	NR	NR	ES	Turkey	Qual	Observation	Learning Basics of Electricity	-	Low cost circuit kit Using Toy Blocks	LSI	CS	Made circuit construction engaging and accessible for children.
Chiu et al. [44]	1	32	8	8	ES	Taiwan	Mixed	Pre- and Post-Tests, Interviews	Learning Electricity	Non-Analogy	Single Analogy	RBIS	CCS	Complementary Analogies group had best performance results among four groups.
	2			8							Similar Analogies			
	3			8							Complementary Analogies			
Cunningham et al. [36]		2880	NR	NR	ES	USA	Quan	Standardized Pre/Post Multiple-Choice Tests	Learning electrical circuits concepts	-	EiE Curriculum in K-12 Classrooms	LSI	CS	Students in treatment group had better outcomes. More learning gains in Electrical Unit than in other science units
Dickerson [39]		20	0	20	HS	USA	Mixed	5-item Likert Scale for four questions, Open-Ended Feedback	Interest in pursuing career in ECE and engagement	-	IoT Workshop using Simblee development kit	LSI	MCS	↑ Student engagement in IoT ↑ in students' interest in pursuing ECE

Jaakkola et al. [45]	1	22	0	22	ES	Finland	Mixed	Pre- and Post-Subject Knowledge Test, Interview	The effect of different educational activities on students' electrical understanding	-	Using Laboratory Exercise	RBIS	DL	All three learning environments showed improvement from pre-test to post-test. However, students who participated in the third intervention demonstrated the strongest learning outcomes compared to the other groups.
	2	20	0	20							Using Computer Simulation	RBIS	DL	
	3	22	0	22							A combination of the Simulation and Laboratory	RBIS	DL	
Jaakkola et al. [7]	1	12	0	12	MS	Finland	Mixed	Pre-post Test, Interview	Learning and Understanding of Electric Circuits	EET Simulation	with Implicit Instruction	RBIS	CS	Least effective outcome
	2	14	0	14							with Explicit Instruction	RBIS	DL	Moderate improvement yet not very effective as in the combined groups,
	3	12	0	12						Both EET Simulation and Hands-on LEK	with Implicit Instruction	RBIS	DL	Highest gain in knowledge,
	4	12	0	12							with Explicit Instruction	RBIS	DL	Gain was only less compared to the former, increased learning time, thus decreased efficiency
Ntourou et al. [38]		33	18	15	MS	Greece	Mixed	Open- and Closed-Ended Questions	Learning Electricity Concepts	Physical & computer Experiments	Arduino and Scratch for Arduino	MI	FI	Computer experiments contributed significantly to the learning process.
Olde et al. [46]		19	0	19	HS	Netherland	Mixed	Observation Simulation Assignment	Learning Electricity Concepts	-	Student assignments using SIMQUEST	RBIS	CL	↑ Ability to retrieve and explain problem-solving steps of circuits.
Peppler, & Glosson [47]		17	0	17	ES	USA	Mixed	Circuit Diagram Assessment, Pre-Post Tests	Understanding of Circuit Diagrams, Current Flow, Connections, Polarity	-	E-textiles toolkit	LSI	CS	↑ Significant gains in understanding circuit diagrams, current flow, connections, and polarity
Peppler et al. [28]		45	0	45	ES	USA	Qual	Observation, Discussion	Conceptions of Circuitry	-	Squishy Circuits toolkit	LSI	CS	↑ Verbalization of circuit concepts
Ramirez-Salgado et al. [35]		7	0	7	HS	USA	Mixed	System Usability Scale (SUS), Open-ended questions	Engagement, Understanding of hardware concepts	-	FPGA Board Game	MI	TVI	Good engagement ↓ Below average SUS score (61) of students
Reisslein et al. [34]	1	41	20	21	ES	USA	Quan	Paper & Pencil post-test, Survey	Knowledge	Snap Circuit Kit: Abstract Representation	Snap Circuit Kit: Concrete Representation	RBIS	DL	↔No significant difference
	2								Enjoyment			MI	PVI	↔No significant difference
	3								Understanding			LSI	CS	Significant difference
	4								Cognitive			LSI	MCS	Significant difference
	5	91	44	47	HS				Knowledge			RBIS	DL	↔No significant difference
	6								Enjoyment			MI	PVI	↔No significant difference
	7								Understanding			LSI	CS	↔No significant difference
	8								Cognitive			LSI	MCS	↔No significant difference

Saba et al. [48]		56	23	33	MS	Israel	Mixed	Pre-post interviews, Open-ended questions	Mental models in the understanding of electric circuits	Regular Science Curriculum	ABM Platform (MMM) with 'Moving with Electrons' unit	RBIS	CCS	Significant advancement in mental models of the treatment group
Saehana et al. [49]		NR	NR	NR	HS	Indonesia	Quan	Likert scale items	Engagement, Understanding of circuits	-	Simple IPA Kit using puzzle blocks	LSI	CS	Met the criteria of feasible learning media, 84% students liked the developed kit.
Skoumios et al. [50]		72	38	34	MS	Greece	Qual	Open-ended questions	Concept (claim), Knowledge (Evidence), and Understanding (reasoning) of Circuits	Guided Research Teaching Model	5E-Model (Constructivist approach to learning)	MI	TVI	↑ Significant improvement was made from pre-test to post-test.
Tofel-Grehl et al. [51]	1	155	NR	NR	MS	USA	Mixed	Pre-and Post-MCQ tests, Interview	Motivation, Engagement	Controlled curricular Units	E-textile units	MI	PVI	↑ The treatment group developed more motivation and engagement.
	2								Learning Circuits			LSI	CS	↔ ANCOVA showed no significant difference in performance.
Tsihouridis et al. [52]		65	33	32	HS	Greece	Mixed	DIRECT test, Interviews	Understanding of electric circuits	Switching from virtual to real labs	Switching from real to virtual labs	LSI	MGS	Switching from real to virtual labs had a slightly better effect on learning.
Young et al. [53]		399	173	226	ES	USA	Quan	Close-ended Questions	Understanding of Circuits	Non-kit curriculum	Kit Based Inquiry Science Curriculum	LSI	CS	Although the treatment group maintained higher scores relatively, ↔ No significant gains between pretest and posttest.
Zulkarnain et al. [54]		50	0	50	MS	Indonesia	Quan	Pre-post Tests, CPAM	Understanding of Electricity, Creativity	-	Paper Circuit Project-Based Learning	RBIS	CL	100% success rate: ↑ Concept Understanding ↑ Creativity

Note.↑ = Increase; ↔ = No Change; ↓ = Decrease; # = Study ID; CCS = Conceptual Changed Strategies; CE = Cognitive Expressive; Chr = Character; CI = Cognitive Interventions; CL = Cooperative Learnings; Cgn = Cognitive; Clm = Claim; CPAM = Creativity Product Analysis Matrix; CS = Cognitive Strategies; CSAP = Colorado Student Assessment Program; DC = Direct Current; DIRECT = Determining and Interpreting Resistive Electric Circuit; ECE = Electronics and Communication Engineering; EE = Electrical Engineering; EET = Electricity Exploration Tool; EiE = Engineering is Elementary; Elec & Geo-Tech = Electrical and Geotechnical; Enj = Enjoyment; ES = Elementary School; Evdns = Evidence; Exp = Experimental; FI = Framing Interventions; FPGA = Field-Programmable Gate Array; HS = High School; IBL = Inquiry Based Learning; IoT = Internet of Things; Knwlg = Knowledge; LEK = Laboratory Equipment Kit; LSI = Learning Strategy Interventions; MCS = Metacognitive Strategies; MGS = Management Strategies; MI = Motivational Interventions; NR = Not Reported; PD = Potential Difference; Perf = Performance; PS = Pre-school; PVI = Personal Value Interventions; Qual = Qualitative; Quan = Quantitative; RBIS = Practice Based/ Research Based Instructional Strategies; RM = Research Method; Rsng = Reasoning; SE = Situational Expressive; SI = Situational Instrumental; SL = Student Levels; Sub = Sub-category; STEM = Science, Technology, Engineering and Mathematics; TVI = Task Value Interventions; Und = Understanding