Flipped Classroom in Science Education Improving Students' Conceptual Understanding of Electrical Energy

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Abstract

The flipped classroom (FC) approach provides students with the opportunity to actively engage in the learning process, while the teacher's role is transformed into that of a supportive facilitator with reduced direct intervention. The implementation of the FC model contributes significantly to the improvement of both teaching and learning processes, particularly in the fields of applied sciences and technology, as demonstrated by the findings of this study. This research investigates the application of the flipped classroom approach among lower secondary school students, aiming to enhance their understanding of fundamental concepts of electricity in Physical Sciences. To achieve this goal, a quantitative study was conducted using the D.I.R.E.C.T. v1.1 questionnaire for data collection. The study involved 135 students from an Experimental Junior High School in Magnesia (Thessaly, Greece), and the data were analyzed using the SPSS statistical software. The results revealed a significant improvement in students' comprehension of concepts such as voltage, electric current, and resistor networks among those taught through the flipped classroom model. Furthermore, the findings confirm that this method effectively addresses the educational challenges of the 21st century, by integrating instruction with the use of modern technological tools.

Keywords: flipped classroom, 21st-century skills, computational thinking, STEM

1. Introduction

Differentiated instruction has been shown to exert a positive impact on students' learning outcomes, including in subjects such as Technology Education (Plageras et al., 2021). Students taught through differentiated strategies demonstrate higher academic achievement compared to those exposed to traditional teaching methods. Consequently, differentiated instruction represents a promising pedagogical approach that accommodates the diverse needs and abilities of all learners, promoting active engagement and inclusive education.

Within this framework, the flipped classroom (FC) emerges as an effective method of instructional differentiation, offering significant learning benefits, especially for students who face difficulties in understanding complex concepts during conventional instruction. This approach highlights students' diversity and individual strengths, while responding to the increasing heterogeneity of modern classrooms. The flipped classroom has proven particularly effective in applied sciences, as it promotes the practical application of knowledge, collaborative problem solving, and peer interaction, surpassing the possibilities of traditional teaching.

In recent years, higher education has faced challenges related to students' limited critical thinking skills (AlJaser, 2017). At the same time, 21st-century technologies have profoundly transformed the learning environment, providing unlimited access to information and educational resources through devices such as computers, laptops, and smartphones (Fu, 2013). The integration of these tools in education enables learners to interact actively with learning content, both in the classroom and remotely (Fisher, 2009).

A growing body of research underscores the importance of learner-centered approaches that foster collaboration, creativity, and cognitive development (AlJaser, 2017; Järvenoja, 2010; Songhao, 2011). Collaborative learning nurtures students' metacognitive skills, enhances communication, and promotes initiative-taking, differentiating itself from the competitive and individualistic nature of traditional learning environments. The incorporation of technology and Web 2.0 digital tools creates new opportunities for knowledge co-construction, idea sharing, and peer interaction (Halili & Sulaiman, 2019).

According to Bloom's taxonomy of the cognitive domain, the flipped classroom model relocates lower-order cognitive tasks (knowledge, comprehension) outside the classroom, allowing in-class time to focus on higher-order skills such as application, analysis, synthesis, and evaluation (Brame, 2013; Krathwohl & Anderson, 2010). In this way, students assume an active role in their own learning process, while the teacher acts as a facilitator and guide (Sams & Bergmann, 2012).

The flipped classroom combines face-to-face instruction with distance learning, integrating features of blended education (Halili & Zainuddin, 2015). Students engage with theoretical content outside the classroom through digital lectures and videos, and utilize in-class time for discussion, experimentation, and problem-solving. This shift in learning dynamics promotes collaboration, autonomy, and creative engagement, while improving overall learning effectiveness (Bishop & Verleger, 2013).

Furthermore, technology integration within the flipped classroom encourages multi-dimensional interaction:

- between student and content,
- between student and teacher,
- between students, and, according to Hillman et al. (1994),
- between students and technological tools.

These forms of interaction are critical for the successful design of a flipped class-room learning scenario (Moore, 1989). Empirical studies demonstrate that the use of educational technology enhances communication, idea exchange, and collaboration, both within and beyond the classroom (Roach, 2014; Kim et al., 2014).

Ultimately, the flipped classroom constitutes a modern pedagogical framework that combines asynchronous digital learning activities—such as comprehension and reflection—with collaborative, creative, problem-solving tasks conducted during face-to-face sessions. It represents a dynamic synthesis of constructivist and behaviorist learning theories, leveraging the strengths of both approaches to enhance teaching effectiveness and student learning outcomes (Bishop & Verleger, 2013).

2. Method

The purpose of this study is to investigate the impact of two different teaching methods on the instruction of the unit on electrical circuits. More specifically, it aims to examine the extent to which lesson design and the active involvement of students in the creation and construction of electrical circuit models within the school laboratory can enhance their conceptual understanding.

This process, combined with appropriate theoretical guidance, can be implemented both in-person and through distance learning, adapting effectively to the needs of the modern educational context.

By employing the flipped classroom (FC) teaching approach, the present study seeks to determine whether there are significant differences in conceptual under-standing between students in the experimental group (EG), who were taught using the flipped classroom model, and those in the control group (CG), who received instruction through traditional teaching methods.

Finally, the study examines whether differentiated instruction through the flipped classroom, combined with the use of Web 2.0 educational tools (such as microcontrollers and sensors), can further contribute to improving students' conceptual understanding of electrical circuits.

Research Questions

The study focuses on addressing the following research questions:

Are there differences in students' learning outcomes resulting from the implementation of the flipped classroom approach compared to traditional instruction?

Do students' learning outcomes differ when the level of problem-solving difficulty is increased under the flipped classroom model?

3. Results

The analysis of mean scores was conducted to examine differences in the number of correct responses before and after the instructional intervention, taking into account both the group of participation (experimental vs. control) and gender.

In the control group, the mean number of correct responses remained low both before (M = 1.43) and after the intervention (M = 1.73), with minimal variation be-tween male and female students. In contrast, the experimental group demonstrated a substantial improvement. Specifically, while the pre-intervention performance was relatively low (M = 1.19), it increased significantly after the implementation of the flipped classroom approach (M = 9.14).

Overall, the findings indicate that students in the experimental group showed clear improvement in their understanding of key concepts, whereas the control group maintained relatively low performance levels. These results suggest that the instructional intervention had a positive effect on the learning outcomes of students in the experimental group, regardless of gender, while no comparable progress was observed in the control group.

Table 1 presents the mean values, standard deviations, medians, value ranges, and reliability indices for the three core content areas: Resistor Networks, Voltage, and Current, both before and after the educational intervention. As shown, mean scores are markedly higher following the intervention, confirming an overall improvement in students' performance.

Moreover, the Cronbach's Alpha coefficients, ranging from 0.947 to 0.979, indicate very high internal consistency and reliability across the content areas, both pre- and post-intervention. These findings reinforce the validity of the measurements and confirm the reliability of the research instrument.

Table 1. Standard deviations, medians, ranges and reliability indices

	Average price	Standard deviation	Median	Range	Cronbach's alpha
Resistor connection PRE	.28	.96	.00	4.00	.947
Resistor connection POST	.81	1.31	.00	3.00	.978
Voltage PRE	.20	.71	.00	3.00	.952
Voltage POST	.83	1.32	.00	3.00	.979
Current PRE	.15	.51	.00	2.00	.953
Current POST	.52	.87	.00	2.00	.976

Table 2 presents the results of the analysis regarding students' understanding of resistor networks before and after the instructional intervention, differentiated by group.

In the control group, the mean score before the intervention was 0.32 (SD = 0.99), which slightly decreased to 0.22 (SD = 0.76) after the intervention. The median remained constant (0.00), and the range of scores narrowed from 4.00 to 3.00. The Wilcoxon signed-rank test revealed a statistically significant difference (p = .011), which nevertheless indicates a slight decrease in performance within the control group.

Conversely, the experimental group demonstrated a clear improvement. The mean score prior to the intervention was 0.25 (SD = 0.93), increasing substantially to 1.41 (SD = 1.47) after the implementation of the flipped classroom model. The median remained at 0.00, while the range of values was stable at 3.00. The Wilcoxon test con-firmed that this difference was statistically significant (T = 766.0, $p < .001$), indicating a substantial enhancement in students' performance.

Overall, the findings suggest that the implementation of the flipped classroom approach had a positive effect on students' understanding of resistor network concepts, leading to significant progress among those in the experimental group, while no comparable improvement was observed in the control group.

Table 2. Description of results regarding resistance connections before and after the intervention per group

			N	Average	Standard deviation	Median	Range	Related-Samples Wilcoxon	p
Group	Control Group	Resistor connection PRE	81	.32	.99	.00	4.00	.000	.011
		Resistor connection POST	81	.22	.76	.00	3.00		
	Experimental Group	Resistor connection PRE	81	.25	.93	.00	4.00	766.0	<.001
		Resistor connection POST	81	1.41	1.47	.00	3.00		

Gender-Based Analysis of Resistor Network Performance

Table 3 presents the results of the analysis of the same dataset as the previous table, this time considering the gender factor.

In the control group, boys had a mean score of 0.29 (SD = 0.93) before and 0.24 (SD = 0.82) after the intervention, with no statistically significant difference (p = .157). In contrast, the boys in the experimental group demonstrated a significant improvement, as their mean score increased from 0.27 (SD = 0.99) before to 1.33 (SD = 1.49) after the intervention. The Wilcoxon test confirmed that this difference was statistically significant (T = 150.0, p < .001).

Similarly, among girls in the control group, the mean score slightly decreased from 0.35 (SD = 1.04) before to 0.21 (SD = 0.71) after the intervention, with the difference being statistically significant (p = .034), indicating a minor decline in performance. Conversely, the girls in the experimental group exhibited substantial progress, as their mean score rose from 0.22 (SD = 0.88) to 1.49 (SD = 1.47). The Wilcoxon test also indicated a statistically significant improvement (T = 248.0, p < .001).

These findings demonstrate that the educational intervention effectively enhanced the performance of both genders in the experimental group, while no meaningful improvement was observed in the control group. Therefore, the implementation of the flipped classroom approach proved to be equally effective for male and female students, promoting equitable learning progress across genders.

Table 3. Description of results regarding resistance connectivity before and after the intervention by group and gender

			N	Average	Standard deviation	Median	Range	Related-Samples Wilcoxon	p
Boys	Control Group	Resistor connection PRE	38	.29	.93	.00	4.00	.000	.157
		Resistor connection POST	38	.24	.82	.00	3.00		
	Experimental Group	Resistor connection PRE	40	.27	.99	.00	4.00	150.0	<.001
		Resistor connection POST	40	1.33	1.49	.00	3.00		
Girls	Control Group	Resistor connection PRE	43	.35	1.04	.00	4.00	.000	.034
		Resistor connection POST	43	.21	.71	.00	3.00		
	Experimental Group	Resistor connection PRE	41	.22	.88	.00	4.00	248.0	<.001
		Resistor connection POST	41	1.49	1.47	1.00	3.00		

Analysis of Students' Understanding of Voltage

Table 4 presents the results of the analysis concerning the concept of Voltage, be-fore and after the educational intervention, differentiated by group.

In the control group, the mean score before the intervention was 0.22 (SD = 0.74) and slightly increased to 0.27 (SD = 0.82) afterward. The median remained 0.00, and the range was constant (3.00) in both measurements. The Wilcoxon test revealed no statistically significant difference (T = 6.0, p = .102), indicating that the intervention had no substantial effect on the control group's performance.

In contrast, the experimental group demonstrated a clear improvement. The mean score before the intervention was 0.17 (SD = 0.69), which increased significantly to 1.40 (SD = 1.48) following the implementation of the flipped classroom model. The median remained 0.00, with the range again constant at 3.00. The Wilcoxon test con-firmed that this difference was statistically significant (T = 630.0, p < .001), indicating a notable enhancement in students' performance.

Overall, these findings show that the experimental group exhibited a significant advancement in understanding the concept of Voltage after the intervention, while the control group displayed no meaningful change.

Table 4. Description of results in terms of voltage before and after the intervention per group

			N	Average	Standard deviation	Median	Range	Related-Samples Wilcoxon	p
Group	Control Group	Voltage PRE	81	.22	.74	.00	3.00	6.0	.102
		Voltage POST	81	.27	.82	.00	3.00		
	Experimental Group	Voltage PRE	81	.17	.69	.00	3.00	630.0	<.001
		Voltage POST	81	1.40	1.48	.00	3.00		

Gender-Based Analysis of Voltage Understanding

Table 5 presents the analysis of the same variable — Voltage — differentiated by gender and group participation.

Among boys in the control group, the mean score before the intervention was 0.26 (SD = 0.83) and increased slightly to 0.34 (SD = 0.94) afterward. However, this difference was not statistically significant (p = .180). In contrast, the boys in the experimental group exhibited a clear improvement, as the mean score rose from 0.15 (SD = 0.66) before to 1.30 (SD = 1.49) after the intervention. The Wilcoxon test confirmed the statistical significance of this difference (T = 136.0, p < .001).

A similar pattern was observed among girls. In the control group, the mean score was 0.19 (SD = 0.66) before and 0.21 (SD = 0.71) after the intervention, showing no statistically significant difference (p = .317). However, the girls in the experimental group demonstrated a substantial improvement, as their mean score increased from 0.20 (SD = 0.71) to 1.49 (SD = 1.49). The Wilcoxon test revealed that this improvement was statistically significant (T = 190.0, p < .001).

Overall, the results indicate that the implementation of the flipped classroom model had a significant positive impact on students' understanding of Voltage for both genders, but only within the experimental group, while the control group showed no notable change.

Table 5. Description of results in terms of voltage before and after the intervention by group and gender

			N	Average	Standard deviation	Median	Range	Related-Samples Wilcoxon	p
Boys	Control Group	Voltage PRE	38	.26	.83	.00	3.00	3.0	.180
		Voltage POST	38	.34	.94	.00	3.00		
	Experimental Group	Voltage PRE	40	.15	.66	.00	3.00	136.0	<.001
		Voltage POST	40	1.30	1.49	.00	3.00		
Girls	Control Group	Voltage PRE	43	.19	.66	.00	3.00	1.0	.317
		Voltage POST	43	.21	.71	.00	3.00		
	Experimental Group	Voltage PRE	41	.20	.71	.00	3.00	190.0	<.001
		Voltage POST	41	1.49	1.49	2.00	3.00		

Analysis of Students' Understanding of Electric Current

Table 6 presents the results of the analysis concerning the concept of Electric Current, before and after the educational intervention, differentiated by group.

In the control group, the mean score before the intervention was 0.17 (SD = 0.57) and slightly decreased to 0.15 (SD = 0.50) afterward. The median remained 0.00, and the range was consistent at 2.00 for both measurements. The Wilcoxon test revealed no statistically significant difference (p = .157), indicating that the intervention had no meaningful impact on the performance of students in the control group.

In contrast, the experimental group showed a marked improvement. The mean score before the intervention was 0.12 (SD = 0.46), increasing to 0.90 (SD = 1.00) after the implementation of the flipped classroom model. The median remained 0.00, and the range was stable at 2.00. The Wilcoxon test confirmed that this improvement was statistically significant (T = 561.0, p < .001), indicating a substantial enhancement in students' understanding of the concept of Electric Current.

Overall, the findings demonstrate that the experimental group achieved significant conceptual progress in understanding Electric Current following the intervention, while the control group exhibited no notable change.

Table 6. Description of results regarding current before and after the intervention per group

			N	Average	Standard deviation	Median	Range	Related-Samples Wilcoxon	p
Group	Control Group	Current PRE	81	.17	.57	.00	2.00	.000	.157
		Current POST	81	.15	.50	.00	2.00		
	Experimental Group	Current PRE	81	.12	.46	.00	2.00	561.0	<.001
		Current POST	81	.90	1.00	.00	2.00		

Gender-Based Analysis of Electric Current Understanding

Table 7 presents the analysis of the same data differentiated by gender.

Among boys in the control group, the mean score slightly decreased from 0.16 (SD = 0.55) before the intervention to 0.13 (SD = 0.47) after, with no statistically significant difference (p = .317). In contrast, the boys in the experimental group demonstrated a significant improvement, as the mean score increased from 0.13 (SD = 0.46) before to 0.90 (SD = 1.01) after the intervention. The Wilcoxon test indicated that this difference was statistically significant (T = 136.0, p < .001).

A similar trend was observed among girls. In the control group, the mean score slightly declined from 0.19 (SD = 0.59) before to 0.16 (SD = 0.53) after the intervention, showing no statistically significant difference (p = .317). Conversely, in the experimental group, the girls showed a substantial improvement, with their mean score in-creasing from 0.12 (SD = 0.46) to 0.90 (SD = 1.00) after the intervention. The Wilcoxon test confirmed that this improvement was statistically significant (T = 153.0, p < .001).

Overall, the results demonstrate that the flipped classroom intervention had a positive and statistically significant effect on students' understanding of Electric Current for both male and female participants in the experimental group, whereas no meaningful progress was observed in the control group.

Table 7. Description of results in terms of current before and after the intervention by group and gender

			N	Average	Standard deviation	Median	Range	Related-Samples Wilcoxon	p
Boys	Control Group	Current PRE	38	.16	.55	.00	2.00	.000	.317
		Current POST	38	.13	.47	.00	2.00		
	Experimental Group	Current PRE	40	.13	.46	.00	2.00	136.0	<.001
		Current POST	40	.90	1.01	.00	2.00		
Girls	Control Group	Current PRE	43	.19	.59	.00	2.00	.000	.317
		Current POST	43	.16	.53	.00	2.00		
	Experimental Group	Current PRE	41	.12	.46	.00	2.00	153.0	<.001
		Current POST	41	.90	1.00	.00	2.00		

4. Discussion

To describe the demographic characteristics and other categorical variables, both absolute and relative frequencies (counts and percentages) were calculated. Additionally, the reliability coefficient (Cronbach's alpha) was computed for the questionnaire items and the respective dimensions of the instrument.

Furthermore, multiple comparisons were conducted among the dimensions of the flipped classroom model, as well as among the items related to the factors influencing teachers' instructional practices with technology, using the Friedman test.

The comparison of students' responses before and after the intervention was carried out using the Wilcoxon signed-rank test, while the Chi-square (X^2) test was applied to examine possible statistically significant differences between the responses of male and female students.

Finally, multiple regression analyses were performed to investigate the impact of key factors on the dependent variables of the model.

All data analyses were conducted using SPSS software (version 26.0), with the level of statistical significance set at 0.05 for all tests.

5. Conclusions

In summary, the analysis of the results supports the view that the implementation of a STEM-based instructional scenario, employing computational tools such as Ar-duino, ArduBlock, and computer simulations, along with the development of artefacts following the Computational Science Education methodology, had a positive impact on students' Computational Thinking (CT) dimensions. This approach contributed to increased self-confidence and reduced computer-use anxiety, even among lower secondary school students with no prior experience in computational environments.

The study also provides a systematic quantitative evaluation framework that enables the examination of whether a hybrid pedagogical model can enhance conceptual understanding and skill development across different CT dimensions and levels of difficulty.

Students who participated in the intervention took an active role in implementing the activities, proposed problem-solving strategies, and engaged with fundamental CT concepts, such as abstraction, algorithmic thinking, problem decomposition, and pattern recognition. They also designed and developed engineering artefacts using Arduino microcontrollers, gaining insight into the relationship between theoretical knowledge and experimental validation through iterative testing and evaluation of their prototypes.

This study enriches the literature by proposing a practical model for the implementation of Computational Pedagogy, integrating engineering thinking into educational practice and leading to positive academic outcomes. The findings reveal that the model significantly improved students' conceptual understanding in the Physical and Applied Sciences, enhanced creativity, and promoted the practical application of knowledge through constructive, hands-on activities.

The research holds particular significance for secondary education teachers, especially those teaching Technology, but also for Physics and Mathematics educators, as it proposes an approach that effectively bridges theory and practice, reinforcing STEM connectivity.

Given that students in the experimental group correctly answered substantially more items on the D.I.R.E.C.T. v1.1 test compared to the control group, it can be concluded that the use of electronic components and experimentation within virtual laboratories improved learning outcomes — a result consistent with previous research (Fritz et al., 2012).

The findings also align with studies emphasizing the benefits of combining physical and digital representations (Kapici et al., 2019; Papadimitropoulos et al., 2021), particularly when these representations originate from multiple sources (Zacharia & Olympiou, 2011; Olympiou et al., 2013; Zacharia & Michael, 2016).

The integration of virtual laboratories and Web 2.0 educational tools enriched the teaching process, made it more engaging, increased student participation, and improved academic performance in understanding electrical circuit concepts. Further-more, engaging students with real-world problems enhanced their motivation and active participation in the learning process.

The differentiation of instructional methods, achieved through the integration of real and digital educational tools, had a complementary effect, improving learning outcomes (Soldengeld & Schultz, 2008; Heacox, 2018). Students taught through the flipped classroom model achieved higher scores on the circuit evaluation test than those in the control group.

Thus, differentiating instruction — both in terms of methodology and instructional tools — significantly enhances students' understanding of electrical circuit concepts. Enriching the flipped classroom with STEM-based activities and Web 2.0 tools for out-of-class learning proved to be highly effective.

Contrary to some literature suggesting the use of online lectures or digital presentations for out-of-class instruction, this study demonstrated — based on the statistical analysis results (high χ^2 values and $p < .05$) — that students in the experimental group achieved statistically significant higher performance.

Finally, students' engagement with authentic, real-life problems increased their participation levels and activated the learning process. The post-test results con-firmed that the experimental group answered significantly more questions correctly than the control group and performed better in higher-difficulty activities, further demonstrating the effectiveness of the flipped classroom model in enhancing cognitive and metacognitive skills.

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