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INNOVATIVE QR CODE-BASED INTERACTIVE TEACHING MATERIALS IN ELECTRICAL CIRCUIT LEARNING

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ABSTRACT:
This study aims to develop and evaluate the effectiveness of QR code-based interactive teaching materials in improving students' understanding in Electric Circuit courses. The innovation integrates three key components including educational videos, virtual laboratories, and interactive quizzes via Google Forms into a single system accessible through QR code scanning. The research employed a Research and Development (R&D) approach using the ADDIE model. The participants were 55 students enrolled in the Electrical Engineering Education study program. Expert validation confirmed that the developed materials are highly feasible, with scores of 94.68% for instructional media and 96% for technology utilization. Results from small group trials and field testing showed positive responses in terms of ease of use (90%), interactivity (87%), and content relevance (93%). Quantitatively, a significant improvement in student learning outcomes was observed, with an average improvement of 62.67% in post-test scores compared to pre-test. The effect size (Cohen's d = 8.70) indicates an extremely large effect. These findings affirm that integrating QR codes as a bridge between printed and digital media significantly enhances the effectiveness of technical education. The study recommends broader implementation of QR code-based interactive materials in vocational and technical education to support self-directed, flexible, and industry-oriented learning.

Keywords: Interactive Teaching Materials; QR Code; Electrical Circuits; Virtual Laboratory; Instructional Video; Learning Outcomes.

INTRODUCTION

The study of electrical circuits is a fundamental course in electrical engineering that demands a strong conceptual understanding and integrated practical skills. Core topics such as Ohm's law, direct current (DC) and alternating current (AC), and the characteristics of electrical components serve as essential prerequisites for mastering industrial electrical systems. However, the abstract and complex nature of these topics often poses significant challenges in the learning process, especially when instruction relies heavily on conventional, one-way, and less interactive teaching methods.

With the advent of Industry 4.0 and the ongoing digital transformation in higher education, there has been a paradigm shift in teaching and learning approaches (Salvacion et al., 2024). Digital-native students tend to adopt learning styles that are more visual, interactive, and mobile-technology-driven (French & Kennedy, 2017; Jayasekara, 2024). Consequently, engineering education must become more adaptive to digital approaches, emphasizing flexible access, learner autonomy, and the integration of multimodal learning media (Liu, 2023; Srinayana & Praveenchandar, 2024).

In this context, Prykhodkina et al. (2025) assert that technology-based instructional materials such as virtual laboratories provide students with opportunities to apply theoretical knowledge and serve as experiential learning tools to bridge the gap between abstract concepts and real-world applications. One promising technology that supports digital learning is the Quick Response (QR) Code (Santika et al., 2022). QR Codes enable seamless linkage between printed materials and digital content such as instructional videos, virtual laboratories, and evaluative quizzes (Mari et al., 2023). By simply scanning the code using a mobile device, students can access learning materials anytime and anywhere, thereby supporting self-directed and ubiquitous learning (Hernando & Macías, 2023).

Several previous studies have demonstrated the effectiveness of QR Code integration in sustaining student interest and participation (Tsihouridis et al., 2021; Tukhtabayeva et al., 2024). Moreover, QR Code usage has been shown to enhance students' motivation, conceptual understanding, and problem-solving skills (Datta et al., 2024; Solihatin et al., 2021). However, studies that specifically develop QR Code-based instructional materials for engineering education particularly in electrical circuit courses remain limited. Most implementations focus on accessing a single type of content, without fully integrating various complementary and contextually relevant learning resources.

In fact, effective engineering instruction requires the integration of cognitive, affective, and psychomotor domains. Combining QR Codes with instructional videos, virtual laboratory simulations, and interactive quizzes via Google Forms presents a holistic learning approach. Unfortunately, the use of these three elements in an integrated QR Code-based instructional package for engineering education remains unexplored (Chaiyo & Nokham, 2017; Jain & Soni, 2024). This gap highlights the urgent need for innovative interactive learning materials that are not only aligned with technological advancements but also responsive to the needs of engineering students in the digital era.

Therefore, this study aims to design and develop interactive instructional materials based on QR Code technology that integrate three main elements: instructional videos, virtual laboratories, and Google Form-based interactive quizzes, into a cohesive learning system for the electrical circuits course. This innovation is expected to enhance students' active engagement, deepen their conceptual understanding, and make the learning process more flexible, engaging, and aligned with industrial needs. Additionally, the findings of this study are anticipated to offer both conceptual and practical contributions to the development of technology-based instructional media in vocational and higher education contexts.

LITERATURE REVIEW

QR Code technology has gained widespread adoption in education as a means to enhance accessibility and flexibility in learning. Walcott-Bedeau et al. (2020) highlight that QR Codes can reinforce independent learning by providing rapid access to relevant learning resources. This aligns with the findings of Hernández-Beltrán et al. (2023) and Sejati & Sayekti (2023), who affirm that students can study anytime and anywhere, thereby improving the flexibility of time and location in learning. Furthermore, Tan et al. (2023) note that QR Codes represent a low-cost technological solution.

The application of QR Codes in the context of electrical circuit learning becomes increasingly relevant when combined with instructional videos. Luong et al. (2021) and Rufaida & Nurfadilah (2021) emphasize that direct access to instructional videos significantly aids students in grasping abstract engineering concepts. They also note that these media allow students to review content repeatedly as needed. Moreover, Pi et al. (2025) confirm that instructional videos are highly effective in facilitating the understanding of complex and abstract concepts. Thus, integrating instructional videos via QR Codes emerges as a crucial strategy for mastering circuit concepts that require dynamic visualizations.

Another essential component in the development of instructional materials for engineering is the virtual laboratory. Jain & Soni (2024), Iqbal et al. (2020), and Sypsas et al. (2024) assert that virtual laboratories not only offer safe and interactive experiment visualizations but also serve as viable alternatives for remote learning. Digital simulations of current, voltage, and electrical component responses enable students to conduct experiments without physical risks and at a lower cost compared to traditional laboratories.

In addition, assessment systems play a crucial role in interactive learning. Google Forms is widely used in technology-based evaluations due to its ability to provide immediate and automated feedback (Uantrai et al., 2022). In the context of QR Code-based technical learning, Lailaturrahmi et al. (2020) note that integrating Google Forms allows students not only to assess their understanding but also to engage in self-reflection.

Various studies have explored QR Code applications across disciplines, including chemistry (Jumabaeva et al., 2024), mathematics (Ünlü, 2023), language learning (Tsihouridis et al., 2021), and religious studies (Faridah et al., 2018). However, there remains a paucity of comprehensive studies that develop an integrated instructional package combining QR Codes, instructional videos, virtual laboratories, and Google Form-based quizzes particularly for electrical circuit instruction.

Accordingly, this study addresses the gap between theory and practice in the development of instructional media for technical education. The interactive QR Code-based instructional materials developed herein aim not only to enhance access flexibility and student engagement but also to offer theoretical contributions to the development of digital technology-based instructional models in engineering education. To deepen the theoretical foundation of this study, the following section discusses key concepts related to interactive learning media, the use of QR Codes in education, the characteristics of electrical circuit instruction, research gaps, and comparative findings from relevant studies.

Interactive Learning Media

Interactive learning media support self-directed learning and the integration of digital technology, both of which are critical in 21st-century education. These media enable students to learn at their own pace and based on their individual needs, while still receiving constructive feedback. This aligns with the findings of Walcott-Bedeau et al. (2020), who emphasized that technology-based tools such as QR codes and videos can enhance autonomous learning and broaden access to contextually relevant learning resources.

Interactive media are designed to facilitate two-way communication between learners and learning materials through structured interaction. Beyond merely delivering information, these tools promote active student engagement by allowing them to explore content, provide responses, and receive immediate feedback (Sejati & Sayekti, 2023). Key characteristics of interactive media include the stimulation of multiple senses, self-navigation, and the presentation of content in multiple formats such as text, audio, images, videos, and simulations.

In technical education, interactive media play a strategic role by visualizing complex and abstract processes. This makes logical thinking and problem-solving skills more concrete and comprehensible (Safitri & Jupriyanto, 2025). This role is particularly significant in subjects such as Electrical Circuits, where students must grasp indirect concepts like current, voltage, and reactance. Hernández-Beltrán et al. (2023) demonstrated that interactive learning media not only improve conceptual understanding but also strengthen students' retention of the materials.

Thus, interactive learning media serve not only as instructional aids but also as bridges between abstract concepts and concrete learning experiences. Integrating these media into technical course materials particularly in Electrical Circuits is expected to enhance student engagement and overall learning effectiveness.

QR Code in Education

The Quick Response (QR) Code is a two-dimensional code capable of storing various types of information such as text, links, images, videos, and other multimedia content that can be easily accessed using mobile devices. In education, QR codes represent a significant technological innovation, improving accessibility, flexibility, and interactivity in learning processes (Chen et al., 2023).

A key advantage of QR codes lies in their ability to provide instant access to learning resources such as videos, simulations, and interactive exercises. This feature greatly supports independent learning and enhances instructional effectiveness, especially in technical subjects (Hernández-Beltrán et al., 2023; Rufaida & Nurfadilah, 2021; Walcott-Bedeau et al., 2020). QR codes are particularly valuable in facilitating the understanding of abstract concepts, such as those found in electrical theory. Students struggling with technical content can revisit interactive materials through QR codes, enabling deeper and repeated learning (Luong et al., 2021; Rai et al., 2023). Research by Solihatin et al. (2021) even found that integrating QR codes into learning materials increased student learning activity by 46.53%.

The use of QR codes extends beyond technical education, with applications across various disciplines such as mathematics, science, languages, the arts, and religious education. According to Costa & Pacansky-Brock (2023) and Donahue et al. (2023), QR codes embedded in textbooks or handouts offer direct access to supplementary videos and interactive exercises, boosting student satisfaction and learning outcomes. Vascan (2023) added that QR codes can be linked to quizzes, maps, or other multimedia content to enrich learning based on students' preferred learning styles. Sari & Qonita (2024) further emphasized that the flexibility of QR codes in meeting diverse learning needs reinforces inclusivity in education.

QR codes also significantly promote self-directed learning. Students can access materials anytime and anywhere based on their individual needs. Jung & Jung (2024) revealed that video content accessed via QR codes enhances learners' self-efficacy and learning autonomy. Meanwhile, Lee & Omar (2025) found that in the context of Technical and Vocational Education and Training (TVET), QR codes enable the delivery of up-to-date digital materials that support flexible learning.

In addition to academic benefits, QR codes bring administrative efficiency and encourage engagement through gamification. Al-Sababha (2024) noted that QR codes simplify the distribution of learning resources and facilitate attendance tracking. Similarly, Rosmala et al. (2024) demonstrated that QR code-based gamification boosts student motivation and participation. Sari & Qonita (2024) also pointed out that integrating QR codes in education helps foster digital literacy from early education levels. In summary, the use of QR codes in education not only improves access to learning materials but also fosters a more independent, interactive, and inclusive learning culture. These advantages make QR codes a vital pedagogical tool for developing instructional content in the digital era.

Learning Electrical Circuits

Electrical circuit instruction is a fundamental component of the electrical engineering curriculum, encompassing essential concepts such as Ohm's Law, types of electrical currents (direct and alternating), and various components including resistors, capacitors, and inductors. Mastery of this subject requires both cognitive abilities to understand abstract concepts and practical skills to design and analyze real-world circuits (Arifin et al., 2022).

However, numerous studies have revealed that students often struggle to achieve deep understanding of electrical circuits. Common challenges include difficulties in visualizing current flow, comprehending the mathematical relationships within electrical laws, and limited hands-on experience due to inadequate resources and facilities. These issues highlight an urgent need for innovative and adaptive teaching approaches that integrate conceptual understanding with practical experience simultaneously.

One proven strategy to address these challenges is the integration of instructional videos and virtual laboratories. Instructional videos enhance students' learning experiences by combining visual and auditory elements, thereby improving information absorption and retention (Sypsas et al., 2024; Williams et al., 2022). Through videos, students can repeatedly observe complex electrical phenomena and experiments, fostering a more comprehensive grasp of core concepts.

On the other hand, virtual laboratories provide solutions to the limitations of physical lab facilities by offering interactive simulations that replicate real-world experiments. Studies by Sypsas et al. (2024) and Williams et al. (2022) indicate that virtual labs not only overcome logistical barriers but also enhance student engagement and conceptual mastery through exploratory, simulation-based activities.

The combination of instructional videos and virtual laboratories forms an ideal approach to learning electrical circuits. This integration balances theoretical understanding with practical skills effectively (Williams et al., 2022). It not only makes learning more engaging and efficient but also equips students with relevant competencies to meet technical demands in the professional world.

Research Gap

Although QR code technology has been widely researched and applied in general education contexts, there is a notable lack of studies that specifically develop and evaluate its use in technical education particularly in teaching electrical circuits. Most prior studies have focused on subjects like languages, mathematics, and chemistry, where QR codes are usually limited to a single function, such as linking to instructional videos or quizzes.

For instance, Jumabaeva et al. (2024) developed QR code-based chemistry materials to facilitate understanding of organic reactions through video animations. Ünlü (2023) used QR codes in mathematics instruction to provide access to game-based exercises. Tsihouridis et al. (2021) applied QR codes in Greek language learning to connect printed materials with digital audio-visual content. While these studies report improved student engagement, their applications do not extend to technical learning environments, particularly in topics in electricity that require both conceptual understanding and practical skills.

Moreover, although virtual laboratories and digital assessment systems have been increasingly utilized in technical education (Iqbal et al., 2020; Sypsas et al., 2024), their implementation tends to be fragmented. These tools are not yet systematically integrated into a single QR code-based instructional framework. Consequently, students often need to access external links independently to reach virtual labs or complete assessments via learning management systems (LMS), without direct integration into printed materials.

Based on the above discussion, a significant research gap can be identified:

1) Currently, no interactive material integrates QR codes, videos, virtual labs, and quizzes into a single system for technical learning, especially in electrical circuits.

2) To date, no QR code-based approach has been designed specifically to improve understanding of abstract concepts in electrical circuits. Such courses require strong visualization and opportunities for self-directed exploration.

3) Moreover, no studies have been found that comprehensively evaluate the impact of integrating the four components on the direct improvement of engineering students' learning outcomes.

Therefore, this study addresses the identified gap by developing interactive instructional materials based on QR Code technology, which directly connect students to various digital learning resources. These materials are designed to integrate essential components of engineering education, namely: instructional videos, virtual laboratories, and evaluative exercises. Furthermore, this research aims to examine the effectiveness of such integration in improving students' conceptual understanding and learning outcomes in electrical circuit courses.

Comparison Table of Previous Studies

A number of previous studies have explored the use of QR Codes in educational settings; however, most are limited to general subjects such as chemistry, mathematics, and languages, rather than within the context of electrical engineering education. Table 1 presents a comparative overview of relevant prior studies involving the use of QR Codes in educational contexts.

Table 1 Comparison of Previous Studies Related to the Use of QR Codes in Education

No	Researcher & Year	Field of Study	QR Code Integration Into	Key Findings	Limitations (Gap)
1	Jumabaeva et al. (2024)	Organic Chemistry	Animated Videos	Improved understanding of abstract concepts	Not focused on engineering/ electrical circuits
2	Ünlü (2023)	Mathematics	Quiz Games	Increased student motivation	Focused only on evaluation; lacked video/simulation
3	Rai et al. (2023); Rufaida & Nurfadilah (2021)	Electrical Engineering	Video Content	Enhanced understanding of electrical concepts	No integration of virtual laboratory
4	Chaiyo & Nokham (2017)	General Education	Google Forms	Fast feedback and flexible learning	Evaluation only; not integrated into technical courseware
5	This Study (2025)	Electrical Engineering	Video + Virtual Lab + Interactive Quiz	Improved understanding and learning outcomes in electrical circuits	Provides full integration within a single instructional package

Based on the table, it is evident that Jumabaeva et al. (2024)successfully utilized QR codes to access animated videos in organic chemistry, while Ünlü (2023) applied QR codes in mathematics to link students with interactive quiz games. The study by Tsihouridis et al. (2021) focused more on the use of QR codes for accessing audiovisual content in language learning. Although all three studies demonstrated positive impacts on student engagement and motivation, none specifically targeted the development of instructional materials in technical education particularly in topics such as electrical circuits, which are abstract in nature and require experimental visualization.

Furthermore, although some studies have employed virtual laboratories and interactive quizzes using Google Forms (Chaiyo & Nokham, 2017; Sypsas et al., 2024), these components have typically been used in isolation and not integrated into a unified QR code-based instructional system. In other words, no previous studies have specifically developed QR code-based interactive instructional materials for technical education that integrate learning videos, virtual laboratory simulations, and interactive quiz questions via Google Forms into a cohesive learning package. Yet, such materials are crucial for supporting technical education, which demands the integration of theoretical and practical aspects.

Therefore, this study aims to fill this research gap by designing instructional materials that not only enrich digital content but also unify all essential learning components through a single, simple access point—QR codes. Through this approach, electrical engineering students are expected to engage in more structured and autonomous learning, thereby enhancing their conceptual understanding and academic performance in the study of electrical circuits.

METHODOLOGY

Research Design and Approach

This study adopted a Research and Development (R&D) approach using the ADDIE development model, which comprises five systematic stages: Analysis, Design, Development, Implementation, and Evaluation (Cahyadi, 2019). The ADDIE model was selected because it provides a structured yet flexible framework for developing technology-based instructional materials, particularly those that integrate interactive digital media via QR codes in technical education contexts. The primary objective of this approach is to produce interactive instructional materials that are both theoretically sound and practically tested, aimed at enhancing students' understanding of electrical circuit concepts.

Research Context and Participants

The study was conducted in the undergraduate Electrical Engineering Education Program at the Faculty of Engineering, Universitas Negeri Jakarta. A total of 55 students from the even semester of the 2023/2024 academic year participated in this research. The participants were divided into two groups: a limited trial group (small group) consisting of students from the previous academic year, and a field trial group (large group) comprising 30 active students selected purposively. The selection criteria included active participation in lectures, consistent attendance, and engagement in practical assignments during the Electrical Circuits course, ensuring representativeness for the purposes of instructional materials development and testing.

Instruments and Data Collection Techniques

Data were collected using several instruments designed to gather information from multiple sources. First, a validation questionnaire was distributed to one subject matter expert and two instructional media experts, as well as to students, to assess the quality of the instructional materials in terms of usability, interactivity, visual design, and content relevance. Second, pre-test and post-test assessments were administered to measure students' conceptual understanding of electrical circuits before and after using the instructional materials. Third, direct classroom observations and feedback collection were conducted during the implementation phase to obtain qualitative data on the utilization and reception of the materials.

Product Validation Procedures

Product validation was conducted in alignment with the five stages of the ADDIE model as follows:

1) Needs Analysis: assessing the electrical circuit content and the characteristics of the target learners;
2) Instructional Design: structuring learning content and embedding QR codes for accessing instructional videos, virtual laboratories, and evaluative quizzes;
3) Product Development: producing the instructional materials and integrating digital media both technically and pedagogically;
4) Implementation: conducting limited and field trials in the classroom with student participants;
5) Evaluation: including expert validation, student questionnaires, and analysis of learning outcomes to assess the instructional materials' effectiveness. Validation results from three experts, one in electrical engineering and two in instructional technology, indicated that the developed interactive instructional materials were categorized as highly feasible, with an average evaluation score exceeding 95.34% across the assessed aspects of media and technology integration.

Data Analysis Techniques

The collected data were analyzed using a mixed-method approach combining descriptive and inferential statistical analyses. Qualitative descriptive analysis was used to interpret the expert validation results and student feedback narratively. Quantitative descriptive analysis was employed to present data in the form of percentage scores from the evaluation questionnaires regarding students' perceptions and the feasibility of the instructional materials. To determine the effectiveness of the product in enhancing conceptual understanding, a paired sample t-test was conducted on the pre-test and post-test scores. All quantitative analyses were performed using the latest version of the Jamovi statistical software.

Research Ethics

This research was conducted in accordance with ethical principles of academic and educational research. Students participating in the study were fully informed about the objectives, benefits, and nature of their involvement. Participation consent was obtained through a voluntarily signed informed consent form. Formal approval for the study was also secured from the Electrical Engineering Education Program at Universitas Negeri Jakarta. All collected data were treated with confidentiality and used solely for scholarly and educational development purposes, in compliance with established research ethics standards.

RESULTS

Expert Validation Results

The interactive instructional materials based on QR Code technology was validated by three experts including two media experts and one subject matter expert in electrical circuits. The validation aimed to assess the feasibility of the materials in terms of instructional media quality and the integration of technology.

Table 2 Expert Validation Results

Assessed Aspect	Maximum Score	Average Score	Percentage (%)	Category
Instructional Media	25	23.67	94.68%	Highly Feasible
Technology Utilization	25	24.00	96.00%	Highly Feasible

These findings indicate that the instructional materials meets the feasibility standards in terms of content quality, visual presentation, and accessibility of interactive media. The results are consistent with the studies conducted by Solihatin et al. (2021) and Jumabaeva et al. (2024), which demonstrated that integrating QR Codes enhances the quality and appeal of instructional media in technical and science education.

Small Group Trial Results

The trial was conducted with 6 students to assess initial perceptions regarding ease of use, interactivity, visual design, and content relevance.

Table 3 Student Responses in the Small Group Trial

Category	Max Score	Average Score	Percentage (%)	Category
Ease of Use	20	18	90%	Excellent

Interactivity	15	13	87%	Good
Visual Design	15	13	87%	Good
Content Relevance	15	14	93%	Excellent

Students reported that they were able to easily access the instructional videos, virtual laboratories, and interactive quizzes based on Google Forms. The videos provided visual explanations that clarified electrical concepts, while the virtual laboratory enabled experimentation without the risk of damaging equipment. These results reinforce the findings of Lestari et al. (2021) and Anisa & Astriani (2022), which highlight the importance of visual elements and interactive exploration in electrical education.

Field Test Results

The field test was conducted with 30 students. The effectiveness of the instructional materials was evaluated by comparing pre-test and post-test results using a t-test.

Table 4 Student Pre-Test and Post-Test Results

Student Group	Pre-Test Mean	Post-Test Mean	Score Difference	Improvement (%)
Field Test (30)	11.60	18.87	7.27	62,67%

Based on the data in Table 4, the implementation of QR Code-based interactive instructional materials as a medium that facilitates quick and practical access to learning resources had a significant impact on improving student learning outcomes. By simply scanning the QR code, students could instantly access instructional videos, virtual laboratories, and interactive quizzes without the need for manual searching. This clearly reduced technical barriers and enhanced learning convenience, thus motivating students to engage in more independent and continuous learning (Sugiyono, 2017). Consequently, the QR code has become a crucial element in creating interactive and easily accessible instructional materials.

Among the 30 participating students, the average score increased from 11.60 on the pre-test to 18.87 on the post-test, based on a maximum score of 20. This score difference of 7.27 points indicates a substantial improvement in conceptual understanding of electrical circuits. The 62,67% improvement, achieved with low cost, rapid deployment, and on-demand accessibility, highlights the remarkable effectiveness of this instructional method.

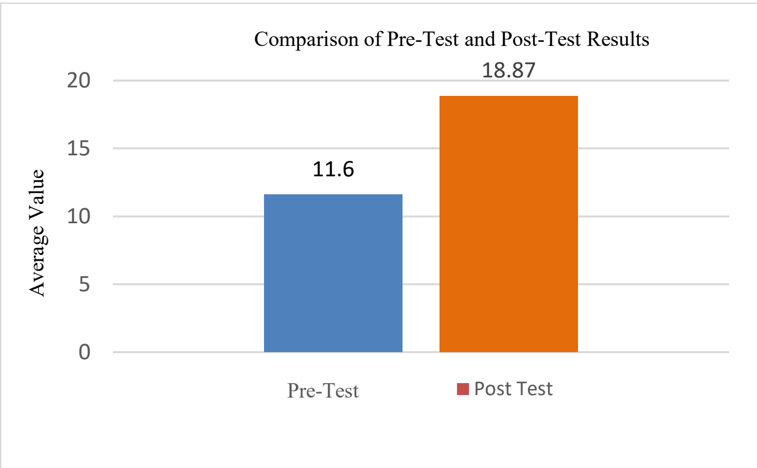

Figure 1 Bar Chart Comparing Pre-Test and Post-Test Results

The following bar chart illustrates the comparison between pre-test and post-test scores. A significant increase in average scores is evident, rising from 45 (pre-test) to 92 (post-test), reflecting the effectiveness of QR Code-based interactive instructional materials in enhancing student understanding of electrical circuit topics. These findings align with the study by Hernández-Beltrán et al. (2023), which found that flexible and interactive digital media in learning environments can enhance student performance and motivation. Puyada et al. (2018) also reported that 90.6% of students who learned using interactive media in electrical circuit topics successfully achieved the minimum mastery threshold, confirming the high effectiveness of such media in improving learning outcomes.

Pre-Test and Post-Test Results

To determine the effectiveness of QR Code-based interactive teaching materials in improving students' learning outcomes, a comparative analysis between pre-test and post-test scores was conducted using a paired sample t-test. The statistical results are presented in the following table 5.

Table 5 Pre-Test and Post-Test Results

Comparison	t statistic	df	p-value	Mean Difference	SE Difference	95% CI (Lower–Upper)	Cohen's d
Pre-Test vs Post-Test	-33.7	29	<.001	-9.27	0.275	-9.83 to -8.70	8.70

Statistical analysis using Jamovi revealed a highly significant difference between students' learning outcomes before (pre-test) and after (post-test) the implementation of the QR code-based instructional intervention, which included educational videos, virtual laboratories, and interactive quizzes. The t-statistic value of -33.7 with 29 degrees of freedom and a p-value < .001 indicates that the observed improvement was not due to chance but rather to the effectiveness of the intervention. The mean difference of -9.27 (on a scale of 20) signifies that post-test scores were substantially higher than pre-test scores. Moreover, the narrow 95% confidence interval (CI: -9.83 to -8.70) strengthens the precision of the estimated treatment effect. Notably, the effect size (Cohen's d = 8.70) falls into the category of a "gigantic effect" as per educational research standards (Sawilowsky, 2009).

These findings align with Mayer's multimedia learning theory (2020), which emphasizes that the integration of visuals (videos), simulations (virtual labs), and feedback (quizzes) fosters deeper and more meaningful learning experiences. The results also corroborate earlier studies employing similar technologies in science and engineering education. Furthermore, these findings are consistent with Al-Azawi et al. (2016), who reported a 68% improvement in learning outcomes (d ≈ 1.5) using augmented reality in electrical circuit instruction, and Fidan & Tuncel (2019), who observed a 72% improvement through the integration of video content into LMS platforms. However, the QR code-based approach in this study yielded a much larger effect size (d = 8.70), indicating not only its effectiveness but also its accessibility and cost-efficiency compared to other educational technology solutions. This supports student-centered learning principles and contributes to the goals of Quality Education (SDG 4) by reducing educational access gaps (Fidan & Tuncel, 2019).

DISCUSSION

This study confirms that teaching materials integrating QR codes, instructional videos, virtual laboratories, and interactive quizzes via Google Forms within a unified system have a positive impact on the effectiveness of technical education. From the perspectives of cognitive and constructivist theories, this instructional approach supports dual-channel information representation (visual, textual, audio) and active exploration through virtual interactions, thereby strengthening students' cognitive schemata. Additionally, the approach promotes self-directed learning, which is vital in vocational education and the context of the Fourth Industrial Revolution. Students are no longer solely dependent on direct instruction from lecturers but are empowered to engage in independent and repeated learning based on their individual needs, as suggested by Rufaida & Nurfadilah (2021) and Rai et al. (2023). However, certain limitations remain particularly regarding dependency on electricity, internet connectivity, and mobile devices. Students with limited access to technology may face challenges in accessing QR code-based content. Hence, future developers should consider providing offline access alternatives or creating hybrid systems to address these accessibility issues.

CONCLUSION

This study aimed to develop and evaluate an interactive instructional materials based on QR codes, integrated with instructional videos, virtual laboratories, and Google Forms–based interactive quizzes to support the teaching of the Electrical Circuits course. Expert validation indicated that the developed product is highly feasible in terms of both content and media. Student trials also revealed positive responses regarding ease of use, interactivity, and content relevance.

Quantitatively, a significant improvement in students' learning outcomes was observed based on the comparison between pre-test and post-test scores, indicating that the QR code-based instructional materials contributed substantially to students' conceptual understanding of electrical circuits. This approach effectively bridges the gap between theoretical and practical aspects of learning in electrical circuit instruction.

The findings of this study suggest that utilizing QR codes as a bridge between print and digital media can be an innovative solution in developing instructional materials for technical education in the digital era. QR codes can expand students' learning opportunities anytime and anywhere expand students' learning opportunities anytime and anywhere typically used in a singular function, enhance active engagement, and support student-centered and self-directed learning. This innovation can serve as a model for developing similar instructional materials, particularly in vocational and technical education.

Despite its promising findings, this study has several limitations. First, the research subjects were limited to a single study program and one course, limiting the generalizability of the results to other contexts or populations. Second, the implementation of the QR code–based instructional materials heavily relies on mobile devices and internet connectivity, which may hinder students with limited access to technology or stable networks. Third, the study focused solely on cognitive learning outcomes, while affective and psychomotor aspects were not examined in depth. Fourth, the study design did not include a control group, preventing direct comparison with conventional teaching methods. Furthermore, evaluation was limited to a short-term measure using an immediate post-test, without assessing long-term retention of conceptual understanding.

Therefore, future studies are encouraged to adopt more rigorous experimental designs, including control groups, and to incorporate delayed post-tests to evaluate the durability of students' understanding. Exploring affective and psychomotor dimensions is also essential to gain a more comprehensive picture of the effectiveness of QR code–based interactive instructional materials.

Based on the above findings and limitations, several recommendations are proposed for future development and implementation. Future research should explore the impact of QR code–based instructional materials on students' psychomotor skills and affective attitudes in electrical practice to provide a more comprehensive understanding of their educational benefits. The implementation of these materials could be expanded to other engineering domains, such as electronics, instrumentation, and power systems, to maximize their utility across different technical fields. Additionally, development of offline or hybrid print-digital versions is recommended to address internet accessibility constraints that may limit the effectiveness of purely digital solutions. Furthermore, integration of QR codes with Learning Management Systems (LMS) or AI-based learning platforms could further enhance the adaptability and personalization of instructional materials.

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