JURNAL EDUSCIENCE (JES)
p-ISSN : 2303 - 355X | e-ISSN : 2685 - 2217
PUBLISHED BY : LPPM of UNIVERSITAS LABUHANBATU

Augmented Reality Media for Learning Electrical Circuits: Enhancing Science Process Skills and Students' Achievement

Nendi Niati[1]*, Rahayu Condro Murti[2], Woro Sri Hastuti[3]

[1,2,3] Primary Education, Faculty of Education and Psychology, Universitas Negeri Yogyakarta
*Email: nendiniati.2022@student.uny.ac.id

ARTICLE INFO

Keywords:
Augmented Reality
Electrical Circuits
Students' Achievement
Science Process Skills

ABSTRACT

Purpose—The study aims to develop Android-based augmented reality (AR) instructional media for teaching electrical circuits, enhancing students' science process skills and learning outcomes. In addition, this technology can help students develop the science process skills needed in science learning.

Methodology—The research was conducted with 29 fifth–grade students at SDN 09 Rangkang, Bengkayang, Using the ADDIE development model (analysis, design, development, implementation, and evaluation). The instruments used at this stage included expert validation sheets, science process skills questionnaires, learning outcome tests, and observation sheets. Data analysis is conducted descriptively and quantitatively to assess the media's validity, practicality, and effectiveness.

Findings – The media's validity was rated highly, with an average expert validation score of 87, while its practicality was deemed suitable, with an average score of 80. The media was also effective as 86% of students achieved high-level science process skills, and 89% met the minimum passing criteria in the learning outcome test, with an average score of 82.

Significance – The results indicate that the developed instructional media is valid, practical, and effective in improving the quality of teaching and learning.

Received 02 December 2024; Received in revised form 06 December 2024; Accepted 15 February 2025
Jurnal Eduscience (JES) Volume 12 No. 1 (2025)
Available online xx February 2025

INTRODUCTION

The continuously evolving technology and information affect various aspects of human life, including education. In this digital era, the role of technology is crucial to ensure a relevant and effective learning process. One of the emerging approaches is STEAM-based learning (Science, Technology, Engineering, Art, and Mathematics), which promotes the integration of various disciplines in education. STEAM learning not only emphasizes knowledge transfer but also focuses on developing critical thinking skills, creativity, and problem-solving, which are essential to preparing a future generation that is competent in technology and

innovation (Aguilera & Ortiz-Revilla, 2021; Hebebci & Usta, 2022). The STEAM approach aligns with the concept of TPACK (Technological Pedagogical Content Knowledge), which combines aspects of pedagogy, content, and technology as a basis for designing innovative learning models that align with current developments (Yeh et al., 2021). The need to respond to educational demands is increasingly urgent, along with the increasing demand for individuals with technological skills and the ability to face complex and multidisciplinary challenges.

Implementing STEAM-based learning with the TPACK approach in Indonesia, especially in border areas like Bengkayang Regency, still faces various challenges. The limited use of technology in learning activities, especially in science subjects involving complex scientific concepts such as electrical circuits, is one of the main obstacles for teachers in the area. Research conducted by Tomczyk and Eger (2020) revealed that the low level of digital literacy among teachers is the main inhibiting factor in implementing TPACK-based learning. In addition, developing innovative learning models requires educators who have teaching competencies and can accommodate diverse students' needs and characteristics. Teachers' psychological readiness and professional skills are important in designing compelling and engaging learning strategies using technology to improve students' scientific literacy (Sánchez-Cruzado et al., 2021).

One learning model widely studied in the context of TPACK is Problem-Based Learning (PBL). This model is oriented towards presenting authentic problems relevant to real-life situations and encourages optimal use of technology to deepen understanding of the material in a more applicable way. A study by Ichsan et al. (2023) revealed that implementing TPACK-based PBL positively improved students' science literacy at elementary to secondary school levels. However, the implementation of this PBL model still faces challenges, especially in terms of the availability and utilization of TPACK-based learning resources, such as syllabi, lesson implementation plans (RPP), student worksheets (LKS), and evaluation instruments that are by learning objectives and the technology used in the teaching process (Ariawan et al., 2022). Therefore, developing locally and contextually based teaching materials is urgently needed to overcome these obstacles and ensure equal access to education in underprivileged areas.

On the other hand, effective learning media is one of the fundamental factors in supporting the success of the learning process. Appropriate media can facilitate interaction between educators and students, making material delivery more systematic, easy to understand, and enjoyable. Research conducted by Ahmad & Junaini (2020) and Rozi et al. (2021) shows that student engagement can be significantly increased through interactive learning media, which ultimately positively impacts their learning outcomes. In this case, using Information and Communication Technology (ICT)-based learning media, such as Augmented Reality (AR), offers great potential, especially in presenting complex and abstract materials, such as the concept of electrical circuits. AR technology allows the visualization of abstract concepts in a more concrete and interactive form, thus supporting students' conceptual understanding and improving their science process skills (Hou et al., 2023; Rino et al., 2023; Saputro et al., 2024).

In Bengkayang Regency, especially at SDN 09 Rangkang, the challenges in learning science, especially in the material of electrical circuits, are still quite significant. The evaluation results of 2023 showed that only 46% of students achieved the minimum completion criteria (KKM) in the formative test related to the material. One of the main factors causing low student learning outcomes is the limited availability of interactive and engaging learning media. This finding indicates an urgent need to reduce the educational gap in border areas through innovative technology. The lack of media that supports conceptual understanding causes students to have difficulty learning abstract concepts, such as electrical circuits, which can be more easily understood with the help of technology (Rahayu et al., 2024). Therefore, the development of augmented reality (AR)-based learning media integrated with information and communication technology (ICT) is a strategic need because it can represent the concept of electrical circuits more concretely and interactively. In addition, this technology can help students develop the science process skills needed in science learning. In line with technological developments and educational demands in border areas, implementing AR-based learning media is expected to improve the quality of learning and student learning outcomes at SDN 09 Rangkang.

METHODOLOGY

This study adopted a development method based on the ADDIE model, which includes five main stages: Analysis, Design, Development, Implementation, and Evaluation (Branch & Stefaniak, 2019). The selection of this approach aims to ensure that the developed learning media meets the criteria of validity, practicality, and effectiveness. In the Analysis stage, student needs and curriculum analysis are identified to determine the essential competencies needed and relevant learning materials, especially related to electrical circuits. The Design stage focuses on developing augmented reality (AR)-based learning media on the Android platform, which includes designing learning flows, interactive scenarios, and visual designs that support the learning process.

The development stage includes the creation of a prototype of the learning media, the validation process by learning media experts, and revisions made based on feedback from the validation process. In the Implementation stage, the learning media was tested on 29 fifth-grade students at SDN 09 Rangkang, Bengkayang Regency, who were selected using a purposive random sampling technique. This technique ensured that the selected participants met specific criteria relevant to the research objectives, such as their grade level and understanding of the material being studied. In addition, this approach allows for a more focused evaluation of the effectiveness of the media in the appropriate context. The instruments used at this stage included expert validation sheets, science process skills questionnaires, learning outcome tests, and observation sheets. The validation sheet aims to assess the feasibility of the developed learning media based on aspects of content, construction, presentation, and language. The test instrument measured student learning outcomes through 10 multiple-choice questions related to electrical circuits. The observation sheet evaluated science process skills based on indicators such as observing, classifying, interpreting, predicting, formulating hypotheses, planning experiments, and communicating (Banchi & Bell, 2022; Bybee, 2023; Padilla, 2021).

The Evaluation Stage aims to assess the effectiveness of the learning media, with the success indicators set, namely, at least 75% of students achieving a high category in science process skills and meeting the Minimum Completion Criteria (KKM) of 75 in learning outcomes. This threshold is determined based on educational standards generally applied at the elementary school level, which require at least three-quarters of students to achieve the competency level set to indicate the effectiveness of the learning intervention. Additionally, the KKM of 75 is aligned with the school's established benchmarks for academic success, ensuring consistency with institutional expectations.

Data analysis is conducted descriptively and quantitatively to assess the media's validity, practicality, and effectiveness. Validity is evaluated based on the average scores from the experts, practicality is measured through teacher assessments of the media's implementation, and effectiveness is analyzed from the achievement of science process skills and students' learning outcomes. The evaluation findings are used to refine the developed learning media. Qualitative data obtained were then converted into a quantitative scale. This guideline assessed the feasibility aspects of the developed electrical circuit learning media. The feasibility assessment is presented in Table 1.

Table 1. Feasibility Assessment

Qualitative Data	Score
Very Feasible	5
Feasible	4
Moderately Feasible	3
Not Feasible	2
Very Not Feasible	1

In terms of practicality, the assessment conversion is presented in Table 2.

Table 2. Practicality Assessment

Qualitative Data	Score
Very Practical	5
Practical	4
Moderately Practical	3
Not Practical	2
Very Not Practical	1

The assessment results for feasibility and practicality aspects are calculated using the following formula.

$$Assessment\ Result = \frac{\sum Obtained\ Score}{\sum Ideal\ Score} \times 100$$

The assessment results are then converted into percentages and criteria based on the qualitative data for the feasibility and practical aspects, as presented in Table 3.

Table 3. Assessment Percentage

Percentage	Feasibility Criteria	Practicality Criteria
81% - 100%	Very Feasible	Very Practical
61% - 80%	Feasible	Practical
41% - 60%	Moderately Feasible	Moderately Practical
21% - 40%	Not Feasible	Not Practical
>20%	Very Not Feasible	Very Not Practical

Based on Table 3, the Android-based Augmented Reality (AR) electrical circuit learning media developed meets the feasibility and practicality criteria if it achieves a percentage of ≥61% and is classified as Feasible for the Feasibility aspect and Practical for the Practicality aspect.

FINDINGS

Analysis Stage

The analysis stage in developing augmented reality (AR)-based learning media aims to identify the appropriate learning needs. The main issue faced is students' difficulty in understanding the concepts of electrical circuits, both theoretically and practically. The school's lack of interactive media and limited laboratory facilities exacerbate this (Julianti et al., 2022). Teachers need innovative, practical, and effective learning media to visualize abstract concepts, while students require an engaging learning experience to support science process skills such as observation and experimentation (Nuraisyah et al., 2021). Android-based media with augmented reality (AR) features is a suitable solution as it offers easy access and interactive visual simulations without physical equipment. This technology is expected to improve students' science process skills, learning outcomes in electrical circuits, and the quality of education in border regions.

Material analysis was conducted to align the learning content with the Merdeka Curriculum implemented at SDN 09 Rangkang. The main topics taught include the basic concepts of simple electrical circuits, both series and parallel and students' abilities in designing and evaluating these circuits. This material encourages students to apply electrical concepts responsibly in everyday life. In addition, a project-based and exploration learning approach is applied to provide a more meaningful learning experience, from introducing basic electrical concepts to practical applications through AR simulations.

Augmented reality media is integrated into learning to provide an interactive visual experience. Students can understand how series and parallel electrical circuits work using animation and simulation. Students can interact virtually with components such as batteries, lights, cables, and switches. Experimental simulations allow students to observe the differences in electric current flow in series and parallel circuits. As part of the project assignment, students must design an electrical circuit model using AR media, encouraging them to apply the concepts they have learned.

The material is also adapted to the context of students' daily lives in border areas. This includes using electricity in households, solving electricity-related problems such as blackouts, and applying relevant examples to the students' surroundings. This approach aims to increase student participation and understanding of the material so that learning becomes more relevant and meaningful (Putri Hapsari et al., 2022; Sadewo et al., 2025; Saputro & Mahmudi, 2020).

The material is structured comprehensively to support the development of the Pancasila Student Profile dimensions, including strengthening students' character and skills. In learning, students are encouraged to use electricity responsibly, reflecting the values of faith and devotion to God Almighty. Independence is developed through activities such as designing and assembling electrical circuits with little guidance, while critical thinking skills are honed through experimental evaluations. Students are also invited to collaborate in groups to complete projects, honing their teamwork and sense of togetherness. Thus, this learning deepens students' conceptual understanding, science process skills, and character values.

Design Stage

The augmented reality (AR)-based learning media for electrical circuits developed is named KABELEDU. This media was created using the Unity application and released in Android format so that it can be easily accessed by users. The initial appearance of KABELEDU is designed with a simple and easy-to-understand interface, making it easy to navigate. This media provides several main menus: guides, materials, augmented reality, and quizzes, each designed to support an interactive and in-depth learning process.

The guide menu provides complete instructions on how to use KABELEDU, especially when utilizing the augmented reality feature. The material menu summarizes learning content about electrical circuits, arranged based on learning objectives. The main feature, the augmented reality menu, offers interactive visual simulations to help students understand the concept of electrical circuits more realistically. In addition, the quiz menu provides practice questions to measure students' understanding of the material studied according to the learning objectives set. KABELEDU is expected to facilitate innovative and engaging student learning with these features. Some of the features of the KABELEDU learning media can be seen in Figure 1.

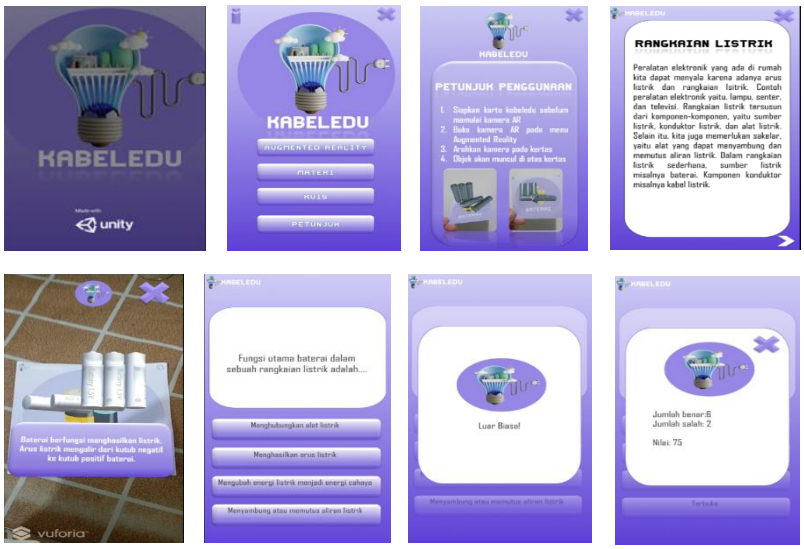

Figure 1. Features of the KABELEDU Learning Media

Development Stage

The development stage of the augmented reality (AR)--based electricity circuit learning media involves expert validation and product revision. Expert validation is conducted to evaluate the developed media's quality, effectiveness, and alignment with learning needs, ensuring that it can be optimally used to support students' understanding of electrical circuit concepts (Safitri, 2024; Safitri, Lestarani, et al., 2024; Safitri, Rosnawati, et al., 2024). The expert involved is typically someone with extensive knowledge and experience in areas such as educational technology, instructional design, and science education, particularly in electrical

circuits. Only one validator is engaged in this process to provide focused and in-depth feedback. This expert is chosen based on their expertise in relevant fields, ability to provide constructive feedback, and experience validating educational media to ensure its effectiveness in an educational setting. The results of the expert validation are presented in Table 4.

Table 4. The Results of the Expert Validation

Component	Validator
KABELEDU Media	100

Based on Table 1, the augmented reality (AR)-based electricity circuit learning media developed has met the Very Feasible, indicating that the media is valid for facilitating science process skills and improving students' learning outcomes. This validation confirms that the Android-based learning media can be effectively implemented to support learning activities related to electricity circuits at the elementary school level.

Although it meets the validity criteria, the analysis of the media's validity revealed some aspects that require revision. The material presented in the media needs to be further aligned with the targeted learning outcomes. Additionally, certain technical elements of the learning media are not functioning optimally and require refinement. The language used in the media also needs to be improved to better match the comprehension level of elementary school students, ensuring that the content is easy to understand and engaging for the learners.

Implementation Stage

In the implementation stage, the augmented reality (AR)-based electrical circuit learning media underwent a limited trial to assess the feasibility of the media that had been developed. This trial involved six fifth-grade students from SDN 09 Rangkang as a sample, which allowed an assessment of how much the learning media could be read and understood. Data were collected through a questionnaire using a Likert scale, which is often used to measure attitudes or perceptions. The Likert scale provides response options from "Strongly Agree" to "Strongly Disagree," allowing participants to state their level of agreement with statements regarding the feasibility of the media. This method ensures a structured and measurable evaluation, providing important insights into how the learning media meets students' needs in a real environment. The results of this limited trial can be seen in Table 5.

Table 5. Results of Limited Trial

Name	Aspects				Sum
	KI	BG	P	K	
S1	12	22	50	22	106
S2	12	23	47	22	104
S3	14	23	52	19	108
S4	12	20	48	19	99
S5	13	25	46	24	108
S6	10	24	44	16	94
Sum	73	137	287	122	
Average					103,17

Description: KI: Content Feasibility; BG: Language and Images; P: Presentation; K: Graphical Design

The analysis shown in Table 5 reveals that the average score of the readability survey for augmented reality (AR)-based learning media on electrical circuits is 103.17, which is included in the convenient category. This shows that the developed learning media is not only effective in supporting science process skills and improving student learning outcomes but is also feasible for further application in field trials.

After improvements were made based on feedback from the limited trial, the next step was to conduct a field trial to assess the feasibility and effectiveness of AR-based learning media on electrical circuits. This trial involved fifth-grade students of SDN 09 Rangkang to evaluate how much the learning media could support science process skills and improve student learning outcomes. Learning activities will be adjusted to the learning objectives set so that the tested media can effectively meet the expected educational objectives.

Evaluation Stage

The practicality of augmented reality (AR)--based learning media for electrical circuits developed based on Android was evaluated through an assessment conducted by teachers. This assessment was conducted using a questionnaire on the ease of use of the learning media that had been developed. The evaluation results showed a score of 47.5, which is relatively high, indicating that this learning media is considered practical in supporting the development of science process skills and improving the learning outcomes of fifth-grade students at SDN 09 Rangkang. This assessment proves that the learning media effectively supports the learning process in the classroom and makes it easy to use according to the desired educational goals.

The effectiveness of this media was measured after a field test based on the results of the science process skills questionnaire and student learning outcome tests. The science process skills questionnaire analysis results showed that 89.66% of students met the "High" criteria for this skill, indicating that the learning media effectively improved science skills. Meanwhile, the learning test analysis results showed that more than 75% of students achieved the passing standard, with an average score of 82.07, exceeding the Minimum Completion Criteria (KKM). These results indicate that the developed learning media successfully facilitated science process skills and significantly improved student learning outcomes at SDN 09 Rangkang.

Receiving feedback and improving learning tools are essential to improving the quality of the learning experience. After the field test, revisions were made to the Android augmented reality (AR)-based learning media developed for teaching electrical circuits. These revisions focused on several key aspects. First, the clarity of the application usage instructions was improved so that teachers and students could easily understand how to use the augmented reality features and the application interface. These adjustments were essential to ensure that the media was easy to use and effective in supporting learning objectives (Fernández-Batanero et al., 2022; Ozturk & Akcay, 2023; Trista & Rusli, 2020).

Second, the content is improved by adding more interactive augmented reality simulations. This new feature aims to present practical scenarios that help students better understand the application of electrical circuit concepts in real life. In addition, improvements are made to the visual design and layout of the application interface to improve aesthetics and ease of use (Handayani et al., 2023; Safitri et al., 2022, 2023; Safitri & Ansyari, 2024). The main goal of these improvements is to provide a smooth and engaging learning experience. The application's evaluation features, such as interactive quizzes and tests, are also improved to more accurately assess student learning outcomes, complete with direct feedback that supports reflective learning (Fatra et al., 2023; Saputro & Mahmudi, 2020).

Finally, compatibility adjustments were made to ensure the app works well on Android devices, including those with low storage capacity and processing power. This is critical to ensuring the app is accessible to all students, regardless of the type of device they use, which will impact the effectiveness and reach of the learning tool across educational settings. This revision demonstrates a commitment to improving augmented reality learning tools' educational quality and user experience. This approach aligns with the growing trend of digital learning environments reflected in recent research on AR applications in education (Kramarenko et al., 2024; Semerikov & Striuk, 2024).

DISCUSSION

Expert evaluation shows that the Augmented Reality (AR)-based learning media for electrical circuits developed meets excellent standards. In addition, the science process skills questionnaire instrument and student learning outcome test were also proven valid, with results showing a high category. This validation indicates that the developed AR-based learning media met the specified validity criteria. The high level of

validity of the instrument indicates that this media is built on a relevant theoretical basis used during its development process.

However, the validation process also underlines the need for improvements to this AR-based learning media based on expert input. The revision is critical to ensure that this product meets the eligibility standards and can be applied effectively in the teaching and learning process. Therefore, this AR-based learning media can be declared suitable for use after improvements are made based on expert advice. This revision process emphasizes the importance of developing educational products that are continuously refined to meet pedagogical needs and ensure their effectiveness.

Research on the development of AR-based learning media on the Android platform for electrical circuit material emphasizes the importance of implementing technology that supports active learning principles in education. AR technology has been proven to provide a comprehensive and interactive experience, allowing students to understand abstract scientific concepts more clearly and easily. Previous research, such as that conducted by Akçayır & Akçayır (2017), has shown that AR can increase student engagement and understanding in STEM education, which is the basis for this study. The validation process in this study further strengthens the fact that the developed learning media meets high-quality standards in terms of material accuracy, design, and suitability for the learning objectives set (Maulana et al., 2022). The validity of this media shows its ability to connect educational theory with functional design, paying attention to user aspects. This results in media that are both scientifically valid and pedagogically effective, as shown by similar research (Ibáñez & Delgado-Kloos, 2018). In addition, this study proves that the developed AR-based learning media can connect theoretical concepts with practical applications in electrical circuits, significantly improving student understanding. By integrating advanced technology into the learning process, these media enable students to learn more engagingly and interactively, in line with the broader educational goal of improving scientific skills (Dilmen & Atalay, 2021; Setiawaty et al., 2024).

The practicality of Augmented Reality (AR)- based learning media integrated with electrical circuit material on the Android platform was evaluated through an assessment conducted by the teacher after all learning sessions were completed. This assessment was based on the teacher's experience using the media in the learning process, including ease of use, effectiveness in delivering material, and its influence on student engagement.

The analysis results showed that this learning media met very high practicality criteria. The evaluation indicated that the media developed could support learning activities effectively and efficiently. Teachers can use this media to deliver material about electrical circuits more interactively and contextually. The high level of practicality indicates that this media is relevant and makes it easy for teachers to manage learning. In addition, this media has been proven to support the development of science process skills and improve student learning outcomes, making it suitable for application in technology-based education.

The results of the practicality test showed that AR-based learning media for electrical circuits on Android is easy for teachers and students to use. Simple navigation features, interactivity offered, and attractive visual elements are the main factors in successfully using this media in the classroom (Sipayung et al., 2020). These factors help users understand and use the media, increasing learning effectiveness. This finding is in line with the research of Artun et al. (2020), which shows that the ease of use and accessibility of AR-based applications directly affect the level of adoption and sustainability of their use in educational environments. The application's ability to provide an easy-to-understand and engaging learning experience is one reason teachers and students receive AR media well. Overall, this practicality test confirms that this AR-based learning media has great potential to be applied in various schools. With ease of use and adequate interactive features, this media can facilitate more effective and engaging learning and support the development of students' science skills.

The effectiveness of Augmented Reality (AR)-based learning media for electrical circuits on the Android platform was analyzed through the science process skills questionnaire and student learning outcome tests. Based on the questionnaire results, 86% of students showed high science process skills, which reflected their ability to observe, analyze, and evaluate electrical circuit concepts well. In addition, the analysis of student learning outcome tests showed that 89% of students achieved complete learning, exceeding the minimum criteria. These findings indicate that the developed learning media effectively supports learning, improves science process skills, and improves student learning outcomes.

These findings also indicate that this learning media helps students understand the theory and allows them to apply concepts in more practical situations. In Bengkayang Regency, which often faces limited resources and infrastructure, the use of this media can significantly impact the quality of education. Research

by Tsai & Wang (2019) also supports these findings, stating that a learning environment using Augmented Reality can increase students' cognitive engagement. AR technology provides a more immersive learning experience, bridging the gap between theoretical knowledge and practical application. In areas such as the Indonesia-Malaysia border, especially in Bengkayang, which has limited access to traditional learning resources, AR-based media can enrich students' learning experiences more engaging and relevantly with current technological developments. By introducing educational technologies like AR, border areas with limited educational resources can experience significant benefits. With the implementation of this media, students in Bengkayang can improve their science process skills and learning outcomes, which in turn better prepares them to face the challenges of education in the digital era.

CONCLUSION

Based on the analysis and discussion results, augmented reality (AR)-based learning media integrated with the Android platform for electrical circuit material has proven to be effective and practical in supporting science process skills and improving student learning outcomes. Revisions made after the field trial resulted in improvements in various aspects, including increasing the clarity of instructions for use, enriching content with additional interactive simulations, and optimizing visual design and user interface. In addition, improvements to the evaluation features and application compatibility with various Android devices also showed significant progress in the effectiveness of this learning media. The results of limited trials and field tests showed that the developed learning media received high ratings from teachers and students regarding the practicality and effectiveness aspects of facilitating electrical circuit learning. With better evaluation features, this application allows for more accurate measurement of learning outcomes and provides feedback that supports students' reflective learning processes. This learning media shows significant implementation potential, especially in integrating augmented reality technology into the elementary education curriculum.

ACKNOWLEDGMENT

We sincerely extend our gratitude to the Master's Program in Primary Education, Faculty of Educational Sciences and Psychology, Universitas Negeri Yogyakarta, for their full support in facilitating and ensuring the smooth progress of this research. We also greatly appreciate all parties at SDN 09 Rangkang for their invaluable cooperation and participation throughout the research process. Without the support from both institutions, this study would not have been completed. May this collaboration continue to flourish and contribute to advancing the field of education.

REFERENCES

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM education and student creativity: A systematic literature review. *Education Sciences*, *11*(7), 331.

Ahmad, N. I. N., & Junaini, S. N. (2020). Augmented reality for learning mathematics: A systematic literature review. *International Journal of Emerging Technology in Learning*, *15*(16), 106–122.

Akçayır, M., & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1–11.

Ariawan, R., Nurmaliza, N., Dahlia, A., Nufus, H., & Nurdin, E. (2022). Validity of Mathematical Critical Thinking Ability Asessment Instruments. *Jurnal Cendekia: Jurnal Pendidikan Matematika*, *6*(3), 2673–2684.

Artun, H., Durukan, A., & Temur, A. (2020). Effects of virtual reality enriched science laboratory activities on pre-service science teachers' science process skills. *Education and Information Technologies*, *25*(6), 5477–5498.

Branch, R. M., & Stefaniak, J. E. (2019). Instructional design theory. *Open and Distance Education Theory Revisited: Implications for the Digital Era*, 85–94.

Dilmen, I., & Atalay, N. (2021). The Effect of the Augmented Reality Applications in Science Class on Students' 21st Century Skills and Basic Skills. *Journal of Science Learning*, *4*(4), 337–346.

Fatra, M., Darmayanti, R., & Dhakal, A. (2023). A study that uses Card based learning media to help students' mathematical literacy. *Delta-Phi: Jurnal Pendidikan Matematika*, *1*(2), 91–98.

Fernández-Batanero, J. M., Montenegro-Rueda, M., & Fernández-Cerero, J. (2022). Use of augmented reality for students with educational needs: a systematic review (2016–2021). *Societies*, *12*(2), 36.

Handayani, N., Safitri, I., & Harahap, R. D. (2023). Studi Kompetensi Guru Nonlinier di Sekolah Menengah Atas. *Jurnal Pendidikan Edutama*, *10*(1), 153–162. https://doi.org/dx.doi.org/10.30734/jpe.v10i1.3004

Hebebci, M. T., & Usta, E. (2022). The effects of integrated STEM education practices on problem solving skills, scientific creativity, and critical thinking dispositions. *Participatory Educational Research*, *9*(6), 358–379.

Hou, H.-T., Fang, Y.-S., & Tang, J. T. (2023). Designing an alternate reality board game with augmented reality and multi-dimensional scaffolding for promoting spatial and logical ability. *Interactive Learning Environments*, *31*(7), 4346–4366.

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education*, *123*, 109–123.

Ichsan, I., Santosa, T. A., Ilwandri, I., & Yastanti, U. (2023). Efektivitas Evaluasi Model CIPP Dalam Pembelajaran IPA di Indonesia: Meta-Analisis. *Jurnal Pendidikan Dan Konseling (JPDK)*, *5*(2), 2423–2430.

Julianti, C., Harahap, R. D., & Safitri, I. (2022). The use of multimedia in biology learning: MAS Subulussalam Sumberjo student responses. *BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan*, *4*(3), 306. https://doi.org/10.20527/bino.v4i3.13812

Kramarenko, T. H., Pylypenko, O. S., & Moiseienko, M. V. (2024). Enhancing mathematics education with GeoGebra and augmented reality. *CEUR Workshop Proceedings*, 117–126.

Maulana, I., Harahap, R. D., & Safitri, I. (2022). Use of learning media through technology for biology education students. *BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan*, *4*(3), 282. https://doi.org/10.20527/bino.v4i3.13418

Nuraisyah, S., Harahap, R. D., & Harahap, D. A. (2021). Analysis of Internet Media Use of Student Biology Learning Interest During COVID-19. *Jurnal Penelitian Pendidikan IPA*, *7*(2), 213–217. https://doi.org/10.29303/jppipa.v7i2.624

Ozturk, E., & Akcay, G. (2023). Can Environmental Education Supported by Augmented Reality (AR) Applications Improve the Environmental Awareness of Primary School Students? *The Eurasia Proceedings of Educational and Social Sciences*, *31*, 216–229.

Putri Hapsari, I., Victor Didik Saputro, T., & Damas Sadewo, Y. (2022). Mathematical Literacy Profile of Elementary School Students in Indonesia: a Scoping Review. *Journal of Educational Learning and Innovation (ELIa)*, *2*(2), 279–295. https://doi.org/10.46229/elia.v2i2.513

Rahayu, W. I., Arif, M. S., Sugiarto, H., & Bibi, S. (2024). Pengembangan interactive virtual laboratory rangkaian listrik dasar sebagai pendukung media pembelajaran. *Jurnal Pendidikan Informatika Dan Sains*, *13*(1), 88–101.

Rino, R., Ariyadi, W., Tri, R., Ahmad, A. A., Astri, W. A., & Khasanah, N. H. (2023). Ethnomathematics augmented reality: Android-based learning multimedia to improve creative thinking skills on geometry. *International Journal of Information and Education Technology*, *13*(4), 731–737.

Rozi, F., Kurniawan, R. R., & Sukmana, F. (2021). Pengembangan media pembelajaran pengenalan bangun ruang berbasis augmented reality pada mata pelajaran matematika. *JIPI (Jurnal Ilmiah Penelitian Dan Pembelajaran Informatika)*, *6*(2), 436–447.

Sadewo, Y. D., Wibawa, B., Hanafi, I., & Purnasari, P. D. (2025). *Enhancing the GROW syntax in GAARANTUNG : a study on the coaching model development in education*. *19*(1), 34–45. https://doi.org/10.11591/edulearn.v19i1.21211

Safitri, I. (2024). Should Likert Data Be Transformed Using Summated Rating Scale? A Confirmatory Factor Analysis Study On The Continuous Learning. *Jurnal Eduscience (JES)*, *11*(3), 790–801. https://doi.org/10.36987/jes.v11i3.6412

Safitri, I., & Ansyari, R. (2024). The Calibration of Science Achievement Test Based on Integrated Islamic Curriculum. *8th International Conference on Education and Multimedia Technology (ICEMT)*, 329–336. https://doi.org/10.1145/3678726.3678727

Safitri, I., Hansyah, P., & Siregar, D. A. (2023). Implementasi Media Pembelajaran Video Animasi IPA Berbasis Karakter Melalui Analogy Learning. *IKA BINA EN PABOLO: PENGABDIAN KEPADA MASYARAKAT*, *3*(1), 42–51. https://doi.org/doi.org/10.36987/ikabinaenpabolo.v3i1.3922

Safitri, I., Lestarani, D., Imtikhanah, R. D. N. W., Akbarini, N. R., Sari, M. W., Fitrah, M., & Hapsan, A. (2024). *TEORI PENGUKURAN DAN EVALUASI*. CV. Ruang Tentor.

Safitri, I., Muti'ah, R., & Sriono. (2022). *Nilai-nilai Karakter pada Siswa SMP (Studi di Kabupaten Labuhanbatu)*. PT. Mega Press Nusantara.

Safitri, I., Rosnawati, R., & Ansyari, R. (2024). Estimasi Kesalahan Pengukuran dalam Penilaian Sidang Skripsi: Generalizability Theory Analysis. *Afeksi: Jurnal Penelitian Dan Evaluasi Pendidikan*, *5*(1), 162–168. https://doi.org/https://doi.org/10.35672/afeksi.v5i1.220

Sánchez-Cruzado, C., Santiago Campión, R., & Sánchez-Compaña, M. T. (2021). Teacher digital literacy: The indisputable challenge after COVID-19. *Sustainability*, *13*(4), 1858.

Saputro, T. V. D., & Mahmudi, A. (2020). Reflective pedagogical paradigm approach in mathematics learning. *Journal of Physics: Conference Series*, *1613*(1), 12007.

Saputro, T. V. D., Purnasari, P. D., Lumbantobing, W. L., & Sadewo, Y. D. (2024). Augmented Reality for Mathematics Learning: Could We Implement It in Elementary School? *Mosharafa: Jurnal Pendidikan Matematika*, *13*(1), 163–174.

Semerikov, S. O., & Striuk, A. M. (2024). Augmented Reality in Education 2023: innovations, applications, and future directions. *CEUR Workshop Proceedings*, 1–22.

Setiawaty, S., Lukman, I. R., Imanda, R., Sudirman, S., & Rauzatuzzikrina, R. (2024). Integrating of Mobile Augmented Reality Applications Through Inquiry Learning to Improve Students' Science Process Skills and Mastery of Science Concept. *Jurnal Pendidikan IPA Indonesia*, *13*(1).

Sipayung, M., Chastanti, I., Harahap, R. D., & Sari, N. F. (2020). Pengembangan media pembelalajaran interaktif berbasis adobe flash terhadap materi sistem pernapasan di SMA Negeri 1 Aekkuasan Kabupaten Asahan. *Jurnal Pendidikan Informatika Dan Sains*, *9*(1), 59. https://doi.org/10.31571/saintek.v9i1.1228

Tomczyk, L., & Eger, L. (2020). *Online safety as a new component of digital literacy for young people*.

Trista, S., & Rusli, A. (2020). HistoriAR: Experience Indonesian history through interactive game and augmented reality. *Bulletin of Electrical Engineering and Informatics*, *9*(4), 1518–1524.

Tsai, C.-H., & Wang, C.-P. (2019). An Analysis of the Development of Cultural Augmented Reality Education in Taiwanese Aboriginal Literature. *Int. J. E-Educ. E-Bus. E-Manag. E-Learn*, *9*, 357–365.

Yeh, Y.-F., Chan, K. K. H., & Hsu, Y.-S. (2021). Toward a framework that connects individual TPACK and collective TPACK: A systematic review of TPACK studies investigating teacher collaborative discourse in the learning by design process. *Computers & Education*, *171*, 104238.