Student Worksheet Based on AR Cells and Tissues to Train Spatial Thinking and Problem Solving

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Abstract

In the contemporary educational landscape of the 21st century, students encounter numerous challenges in cultivating advanced competencies across varied skill sets, notably in spatial thinking ability and problem-solving skills. This study aims to develop an Augmented Reality (AR) application focusing on Cells and Tissues, designed to enhance spatial thinking ability and problem-solving skills among biology students and prospective biology educators during lectures on Plant Development Structures. The objective is to provide practical and effective learning experiences. A key methodological approach is the integration of an augmented reality application, termed "AR Cells and Tissues," which specifically addresses plant anatomy with an emphasis on cells, tissues, and plant organs. The practicality of the application is evaluated through user feedback, while its effectiveness is assessed based on indicators related to spatial thinking ability and problem-solving skills. User satisfaction resulted in a mean score of 3.55, categorizing the application as "Very Practical." Furthermore, the effectiveness metrics reveal that spatial thinking capacity averaged 84.88, categorized as "High," while problem-solving capacity achieved a mean score of 77.73, also indicating a "High" level. These findings suggest that the development and implementation of the AR Cells and Tissues application considerably enhance spatial thinking ability and problem-solving skills, particularly within the realm of biology education.

Keywords: Augmented Reality (AR), spatial thinking, problem solving, biology education, educational technology

1. Introduction

The process of preparing superior human resources through local and international education systems must integrate advanced technology, information, and communication (ICT) (Susantini et al., 2021). The use of technology in education is a crucial component of 21st-century learning. It influences good interaction between educators and students. Learning with this technology can be used to teach various things, such as the structure of plant development and its relationship with anatomical objects. However, it also requires spatial thinking ability, which students must master, especially at the student level.

Students face many problems in the 21st century. As stated by the Indonesian Partnership for 21st Century Skills Standards, the required thinking skills are those of higher-order thinking. Therefore, these abilities must be trained through the learning process, which includes biology learning (Hujjatusnaini et al., 2022). Teachers must have expertise in creating learning experiences that can help develop higher-order thinking Skills (HOTS) (Lilo Adi Sucipto et al., 2025). Spatial thinking ability, a component of creative thinking and problem solving, is a fundamental concept of higher-order thinking Skills (HOTS) and one of the skills that must be possessed immediately. Spatial thinking involves the ability to communicate in a space-based manner as well as the ability to notice and produce detailed images. The ability to think spatially using mental images is one of the interesting aspects to be investigated in this study. Spatial thinking ability is also related to the ability to understand, transform, and recreate aspects of the spatial world. Additionally, spatial thinking ability is also related to the ability to accurately perceive the direction, color, and dimensions of space (Burns & Davenport, 2025).

Augmented reality (AR) technology has shown promise in enhancing spatial thinking and problem-solving skills, particularly in educational contexts. Studies have demonstrated that AR can enhance students' understanding of mathematical concepts and their ability to visualize complex spatial relationships (Guntur et al., 2020). For young children, AR sandboxes have been found to enhance spatial abilities through active manipulation and exploration (George et al., 2020). In construction management education, AR has been perceived positively by students for its ease of use and effectiveness in improving spatial skills learning (Kim & Irizarry, 2021). The integration of AR technology in education aligns with the need to develop essential 21st-century skills, including the use of media and technology. As spatial intelligence is not innate but can be developed, AR offers a dynamic and interactive approach to fostering these crucial abilities across various age groups and disciplines.

In Era 4.0, the technology that can be utilized to develop learning media is applications. Applications provide ease of use that can be accessed anytime and anywhere (Setyawan et al., 2019). One technology that can be integrated with applications is augmented reality (AR). Research shows that Augmented reality (AR) is a technology that integrates factual and abstract elements in computing. AR produces three-dimensional visualizations as an enhancement of the existing reality by embedding digital material (McMillan et al., 2017).

The use of Student Worksheet Based on AR Cells and Tissues technology in interactive learning has expanded the boundaries of traditional learning, integrating the ambiance of real and virtual spaces in real-time. Through AR, students can engage in more engaging learning experiences with vivid visualizations, interactive simulations, and hands-on activities, facilitating a better understanding of complex concepts. Meta-analyses by Saputra and Fajriani (2021) and Xu et al. (2022) demonstrate that the use of AR has a positive impact on student motivation and learning outcomes. In addition, research by Özeren and Top (2023) also confirmed that the use of AR can enhance conceptual understanding. Through AR technology, interactive learning has evolved significantly, freeing learning from the limitations of conventional classrooms and teaching materials. Students now have access to view 3D objects, visualize abstract concepts, and engage in location-based educational activities, encouraging the development of critical thinking, cooperation, and problem-solving skills.

Development Student Worksheet Based on AR Cells and Tissues, applications or software that can help Biology students visualize spatial concepts interactively. Based on the description above, it is necessary to research and develop augmented reality-based applications that present a 3D visualization of abstract material to train and improve spatial thinking skills. The purpose of this research is to develop a feasible augmented reality-based application that enhances spatial thinking ability in plant anatomy materials. This research is worth doing because it can (1) help students and lecturers in carrying out teaching with abstract material; (2) facilitate lecturers and students in obtaining learning media to design learning that can improve spatial thinking ability; (3) improve the quality of learning in Biology Education lectures specifically on plant anatomy mate*rial, to produce graduates who are skilled in solving spatial problems.*

2. Method

The data on the practicality of using the AR Cell and Network Application. Testing is done by giving a response questionnaire to biology students and prospective biology teachers. Response questionnaires are used to determine the response to the use of the Student Worksheet Based on AR Cells and Tissues. The questionnaire was administered and completed by 135 respondents, including 35 students from the 2023 pure biology class and 100 biology teacher candidate students, after all lecture meetings had concluded.

Data on student responses were obtained from the student response scale to the learning process. The next stage was analyzed using both descriptive and quantitative methods, as well as qualitative methods. Data on student responses were obtained from the scale. Data analysis of the student response scale used the Likert scale in the form of positive questions.

The percentage of student responses was converted using the criteria outlined in Table 1.

Table 1. Student Response Percentage Criteria

Percentage (%)	Rating Criteria
90,00 – 100,00	Very good
80,00 – 90,00	Good
70,00 – 79,99	Fair
50,00 – 69,99	Not Good
0,00 – 49,99	Not Good

(Adapted from Hinton, McMurray, & Brownlow, 2015)

The Second dataset consists of data on the effectiveness of using the AR Cell and Tissue application, obtained from 135 samples, in training spatial thinking ability and problem-solving skills. The technique for analyzing spatial thinking ability is the percentage technique, which is then classified based on spatial thinking ability and problem-solving skills, as referred to by Halimah et al. (2022).

Table 2. Spatial Thinking and Problem Solving Assessment Criteria Score Range (%)

Value range (%)	Level
0 – 33.33	Low
33.34 – 66.66	Medium
66.67 - 100	High

3. Results

This research develops augmented reality-based media applications that are feasible for enhancing spatial thinking ability and problem-solving skills in undergraduate biology students and prospective biology teachers of plant anatomy material.

3.1 Practicality of Student Worksheet Based on AR Cells and Tissues: Cell and Tissue Application Trial Results

Based on Figure 1, the last stage is the testing stage, which will test the augmented reality-based application.

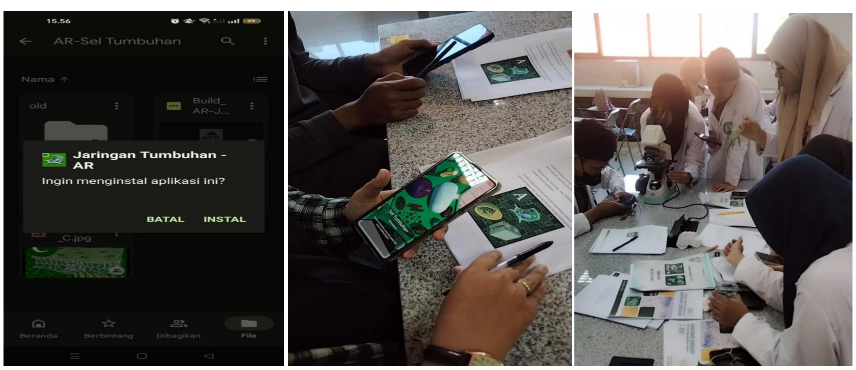

Figure 1. Students install the Student Worksheet Based on AR Cells and Tissues as an initial trial stage (left), Students try to scan Marker A by using the Student Worksheet Based on AR Cells and Tissues that they have installed on their smartphone or cellphone (middle), students make a comparison between the images that have been seen in the Student Worksheet Based on AR Cells and Tissues with the actual object of observation using a microscope. They conduct analysis and discussion based on the results of trials using the Student Worksheet, which is based on AR Cells and Tissues, with the guidance of lecturers (right).

Table 3. Results of the Practicality of Using Student Worksheet Based on AR Cells and Tissues

Indicators of Spatial Thinking Ability (A1-A5) and Problem-Solving Skills (B1-B4)	Description of Cell and Tissue AR App Usage Perspectives	Mean Practicality Score Based on Application Use Response
A1-Spatial Perception	Users can access interactive simulations to improve their ability to recognize spatial patterns and structures.	3.53
A2-Spatial Visualization	Users can visualize plant cells and tissues from various	3.37
A3-Mental Rotation	Users can rotate and view objects of plant cells and tissues from various angles using this technology.	3.46
A4-Spatial Relationship	Users can easily identify the relationship between different parts of plant cells and tissues.	3.56
A5-Spatial Orientation	AR technology helps users with spatial orientation	3.56
B1-Understanding the problem	Users can identify problems in plant cell and tissue materials.	3.53
B2-Making plans	Users can be more confident in finding and planning solutions to problems related to plant cell material after attending lectures.	3.69
B3-Do the plans	Users can be more confident in implementing solutions that have been sought or designed for problems related to plant tissue material after attending lectures.	3.69
B4-Checking back each previous stage	Users can find creative solutions after attending lectures and using the Cell and Tissue AR Application.	3.53
Total Score Mean Practicality of Using AR Cell and Tissue Application		3.55 (Category: Very Practical)

The results of the practicality of using the AR Cell and Tissue application in learning biology demonstrate that this application is efficient and feasible for use as an interactive learning medium (Table 3). Based on user responses, this application received an average score of 3.55, which falls within the "Very Practical" category. Each indicator of spatial thinking ability and problem-solving skills measured showed high and consistent scores. In the spatial thinking aspect, the spatial perception indicator (A1) received a score of 3.53, indicating that the interactive simulation in the application helps users effectively recognize spatial patterns and structures. Spatial visualization (A2) scored 3.37, which is slightly lower than the other indicators but still shows the app's ability to help visualize plant cells and tissues. Mental rotation ability (A3) scored 3.46, showing that users can effectively rotate and observe objects from different angles. Spatial relations (A4) and spatial orientation (A5) each scored the highest among the spatial indicators at 3.56, indicating that the app helps understand the relationships between parts as well as the spatial orientation of biological objects.

Meanwhile, in the aspect of problem-solving skills, the problem understanding indicator (B1) scored 3.53, indicating that the app helped students identify biological problems. The planning (B2) and plan implementation (B3) indicators each scored 3.69, the highest score in their respective categories, which indicates that the app is very effective in building students' confidence to design and implement solutions to the problems they face. The evaluation of the problem-solving stage (B4) also yielded a high score of 3.53, indicating that the app supports the reflective process of the steps taken in problem-solving.

The high practicality demonstrated by the use of AR Cell and Tissue applications in biology learning should be viewed not only as technical ease of use but also as strong evidence that technological innovation plays a crucial role in transforming 21st-century learning methods. In the context of abstract and complex plant anatomy material, conventional approaches such as lectures and two-dimensional images have proven less effective in accommodating students' visual and conceptual needs. Therefore, augmented reality technology is not just a tool but a relevant and visionary pedagogical solution. It not only presents visual objects in three-dimensional form but also allows for direct interaction, stimulating students' cognitive engagement. It is a form of active learning that is proven to be more effective than traditional passive methods.

The high practicality score is also a strong argument that this kind of technology integration supports the achievement of higher-order thinking competencies (HOTS), which is currently the leading indicator of educational success. Students are not only required to understand concepts but are also required to observe, analyze, plan solutions, and evaluate the process. All these activities are reflected in the use of applications that facilitate various stages of thinking and problem-solving skills. Therefore, if learning is to be truly contextual, meaningful, and, given the reality of the digital age, then the use of AR is not only feasible but also urgent. The development and use of AR Cell and Tissue applications should set a precedent that technological innovation in education is not a complement but an essential need in shaping informativeness and future-oriented biology learning.

3.2 Effectiveness of Using Student Worksheet Based on AR Cells and Tissues

The effectiveness of the AR Cell and Tissue application is evident based on the results of achieving indicators of spatial thinking ability and problem-solving skills among pure biology students and prospective biology teachers. Table 4 describes data on the achievement of spatial thinking ability indicators.

Table 4. Recap of Data on Achievement of Spatial Thinking Ability Indicators

Spatial Thinking Ability Trained/Score Gain	A1: Spatial Perception	A2: Spatial Visualization	A3: Mental Rotation	A4: Spatial Relationship	A5: Spatial Orientation
Total Score	11776.36	9900.00	11420.00	12764.71	11431.11
Average Total Score	87.23	73.33	84.59	94.55	84.67
Overall Average			84.88		
Spatial Thinking Indicator Achievement Level = High Category					

The following is data on the achievement of problem-solving skills indicators (Table 5).

Table 5. Recap of Data on Achievement of Problem-Solving Skills Indicators

Spatial Thinking Skills Trained/Score Gain	B1: Understanding The Problem	B2: Making Plans	B3: Do The Plans	B4: Checking Back Each Previous Stage
Total Score	11053.33	10230.00	11609.09	9083.33
Average Total Score	81.88	75.78	85.99	67.28
Overall Average		77.73		
Problem Solving Skill Level = High Category				

Based on Tables 4 and 5, it can be obtained that the spatial thinking ability has a mean of 84.88; this shows that the level of achievement of spatial thinking indicators is in the high category, problem-solving skills have a mean of 77.73 with a high category, this is based on the classification of spatial thinking ability and problem-solving skills referring to (Halimah et al., 2022) that in Table 2. Spatial thinking assessment criteria and problem-solving skills have a value range (%) of 66.67-100 and are therefore included in the high category level. This suggests that the development of AR Cell and Tissue applications has the potential to enhance spatial thinking ability and problem-solving skills, particularly in the field of biology education.

Spatial thinking will play a crucial role in learning problem-solving skills related to plant development, structure, and material, particularly in plant anatomy. Spatial thinking plays a crucial role in learning problem-solving in plant development, particularly in the context of plant anatomy. The use of Student Worksheet Based on AR Cells and

Tissues can be integrated to train spatial thinking. Technology, especially Student Worksheet Based on AR Cells and Tissues, plays a fundamental role in enhancing students' spatial thinking ability and altering their perspective on the world and their interaction with the surrounding environment. However, students still currently face difficulties in meeting the criteria for spatial thinking. The Plant Anatomy course demands a high level of spatial reasoning and the ability to understand abstract 3D structures. However, students often face difficulties in visualizing plant structures, transitioning from two-dimensional (2D) to three-dimensional (3D) representations, as well as understanding the individual parts of tissues and organs within the context of the whole. Better development of spatial thinking ability is needed to facilitate a deeper understanding of plant anatomy. Therefore, it is necessary to develop application media that can provide learning examples to enhance students' spatial thinking ability. The utilization of technology in the field of education has expanded to include the use of Student Worksheet-Based Learning on AR Cells and Tissues. Augmented reality applications offer ease of use through flexibility and accessibility. Recent research has shown support for the use of AR in education, with significant improvements in student learning outcomes (Xu et al., 2022)

Problem-solving skills are also critical in learning biology, as noted by Hariri and Wibawa (2025). This is because these skills focus more on developing thinking skills that are useful in everyday life rather than just learning the material. According to research conducted by Nikolić & Antonijević (2024), students with low and high spatial abilities are unable to reach the level of analytical thinking. (Dahlan et al., 2024) stated that everyone has different ways and abilities to solve problems because not everyone possesses the same abilities. Additionally, a person's ability to solve biological problems is influenced by both internal and external factors.

4. Discussion

Student Worksheet Based on AR Cells and Tissues technology has shown significant potential in enhancing biology education by addressing challenges associated with abstract concepts and traditional teaching methods. AR applications enable students to interact with 3D models of biological structures, thereby improving their understanding and retention of complex topics, such as plant anatomy (Hallaby & Syahputra, 2024). Studies have demonstrated that AR-based learning increases student engagement, motivation, and academic achievement in biology courses (Khalid et al., 2019; Liao et al., 2024). The technology allows for visualization of microscopic and abstract concepts, making learning more interactive and enjoyable (Flavin et al., 2025). AR has been found to promote active learning, independent exploration, and collaboration among students. While some technical challenges exist in implementing AR, such as application distribution, the overall benefits of AR in biology education are substantial, supporting its role as an innovative pedagogical tool for 21st-century learning (Subran & Mahmud, 2024).

Recent studies have shown that Student Worksheet Based on AR Cells and Tissues has a significant impact on the development of higher-order thinking skills (HOTS) in education. In a recent meta-analysis by Lu et al. (2025), it was found that AR has a significant positive influence on strengthening HOTS, particularly in aspects such as three-dimensional visualization and immersive learning experiences. AR's ability to present objects and concepts in real-time through 3D representations allows learners to more easily build a deep understanding of complex and abstract material, such as in biology learning. This is also reinforced by Sylvia et al. (2020), who proved that the use of AR in biology learning resulted in a significant increase in students' pre-test and post-test scores, indicating that this technology is effective in strengthening critical thinking, analytical, and problem-solving skills.

In addition, in the context of physics learning, Bakri et al. (2021) demonstrated that integrating AR with the Technological Pedagogical Content Knowledge (TPACK) framework in the practicum module can support the development of Higher-Order Thinking Skills (HOTS) through the presentation of real-world phenomena and direct data analysis. This is important because TPACK requires teachers not only to master the material but also to understand the appropriate technology and pedagogical strategies, and AR is a tool that bridges these three. Meanwhile, Yuniarti et al. (2024), in a study on vocational teacher education, showed that AR-based learning media had a positive impact not only on academic performance but also on students' independent learning, digital literacy, and critical thinking skills.

Augmented Reality (AR) technology has shown promising effects on students' spatial ability and academic achievement across various educational levels. Studies have demonstrated that AR applications can significantly enhance spatial thinking ability, particularly in subjects such as mathematics and science (Flavin et al., 2025). While some research found no significant difference between AR and traditional methods in enhancing spatial ability, others reported that AR-based learning environments had a more substantial impact on students with low spatial ability (Phon et al., 2015). The technology allows students to manipulate 3D objects in real-time, facilitating a deeper understanding of complex structures and relationships (Barahona & Almulhim, 2024). The implementation of AR in topics such as geometric objects, plant structures, and mangrove roots has resulted in improved learning outcomes and enhanced spatial thinking abilities (Afnan & Puspitawati, 2024; Lu et al., 2025). These findings suggest that AR can be an effective tool for enhancing spatial cognition and academic performance in various educational contexts.

The mental rotation and spatial perception capabilities enhanced through AR not only accelerate concept understanding but also strengthen students' visual reasoning power, a much-needed skill in biology and other natural sciences. In conventional approaches, such an understanding is often hindered by the limitations of two-dimensional media, such as images in textbooks or presentation slides. When students are required to transform 2D information into 3D models in their minds without the aid of interactive visual aids, the potential for cognitive errors and misconceptions increases. Therefore, AR's advantage in providing a dynamic visual learning experience makes it a highly effective pedagogical tool for strengthening spatial thinking ability. The integration of this technology not only addresses the challenge of visual understanding in biology learning but also encourages students to become active learners who can build understanding through exploration and direct interaction with learning objects.

The achievement of an average score of 77.73 in the problem-solving aspect demonstrates that the use of the AR Cell and Tissue application not only enhances the appearance of learning but also actively fosters a systematic thinking process essential for mastering high-order thinking skills (HOTS). This application is designed to guide students through four main stages of problem-solving: understanding the problem (Stage 1), developing a solution plan (Stage 2), implementing the plan (Stage 3), and evaluating the process that has been carried out (Stage 4). These four indicators each score above 67, reflecting that students are not only engaged in rote learning activities but also in cognitive activities that require understanding, planning, execution, and reflection.

For example, in the problem understanding stage (B1), students are trained to critically identify biological problems that arise from AR simulations, such as tissue structures that do not align with their functions. In the next stage, students design solutions (B2) by compiling solution steps based on the visualization analysis carried out through 3D objects in the application. Solution implementation (B3) is achieved through direct interaction within the application and group discussions, while evaluation (B4) encourages students to review the effectiveness of the steps taken and consider possible alternative solutions. This entire process exemplifies the problem-based learning (PBL) approach, which is highly effective in fostering independent, reflective, and critical thinking in students.

The significant problem-solving scores achieved by students through the use of the AR Cell and Tissue application indicate that augmented reality technology is not just a means of delivering learning content visually but a learning ecosystem that triggers active cognitive engagement and is context-based. AR acts as a bridge between theoretical knowledge and empirical experience, where students are not only presented with information but are invited to interact directly with the material through 3D simulations that resemble real objects. In the context of biology learning, especially with plant cell and tissue materials that have high spatial complexity, students are facilitated in making in-depth observations of microscopic structures using AR markers, and then linking them to the results of actual microscope observations in the laboratory. This encourages the integration of observation, comparison, data analysis, and scientific discussion skills. The learning process does not stop at static understanding but evolves into reflective and investigative activities, where students actively build conclusions based on the visual and conceptual evidence they obtain (Dehghani et al., 2023). This activity represents the ideal scientific learning cycle, as contained in the inquiry-based learning approach, namely exploration, experimentation, and reflection. AR, in this case, acts as a trigger that allows students to think systematically, develop hypotheses, test the truth of assumptions, and revise their understanding based on concrete data. This kind of experience clearly cannot be presented in conventional one-way learning, where students are only passive recipients of information. Therefore, the use of AR in biology learning offers substantial pedagogical potential in fostering students' critical thinking, problem-solving, and intellectual independence more fully and meaningfully (Ciloglu & Ustun, 2023).

Augmented Reality (AR) technology has shown significant potential in enhancing inquiry-based learning (IBL) experiences in science education. AR-supported IBL promotes active student engagement, motivating and enjoyable learning experiences, and improved academic achievements (Cai et al., 2023; Umer et al., 2017). The integration of AR in IBL aligns with contemporary learning approaches, leveraging AR's affordances to support the five phases of inquiry-based learning (Pedaste & Mitt, 2020). AR applications in IBL facilitate interactive exploration, data collection, and analysis, enabling students to engage in scientific inquiry processes. Studies have demonstrated that AR-supported IBL leads to more active student responses and higher teacher response rates compared to traditional methods. However, effective implementation requires teachers to develop skills in guiding students and providing timely feedback while using AR tools. Overall, AR technology offers promising opportunities to enhance IBL experiences in science education.

Augmented Reality (AR) is emerging as a transformative technology in education, offering significant potential to enhance learning experiences across various subjects (Gustina & Mariana, 2025). AR aligns with constructivist and experiential learning theories, providing interactive and immersive experiences that enable students to actively construct knowledge. It bridges the gap between abstract concepts and real-world applications, fostering a more profound understanding and retention. Two main approaches in AR-aided science learning are image-based and location-based AR, which afford different benefits such as improving spatial ability, practical skills, and conceptual understanding (Xu et al., 2022). AR's ability to overlay digital content onto the physical world creates engaging, interactive learning environments that cater to the needs of 21st-century learners. However, further research is needed to explore learning experiences, learner characteristics, and the combination of different AR approaches in educational contexts.

5. Conclusion

Based on the study's results, the development of a student worksheet focusing on AR Cells and tissues in plant structure and development has proven to be highly practical and effective in supporting the learning process. In terms of practicality, the use of AR Cell and Tissue applications received an average score of 3.55, which falls within the convenient category. This demonstrates that the application is user-friendly for students, offers an engaging learning experience, and facilitates an understanding of spatial concepts through interactive simulations that can be accessed anytime and anywhere. Features such as three-dimensional object visualization, display rotation, and direct comparison with real microscopic objects are the main advantages of using this application.

From the perspective of effectiveness, the use of this Student Worksheet, based on AR Cells and Tissues, has been proven to significantly improve students' spatial thinking abilities and problem-solving skills. Spatial thinking ability yields an average score of 84.88, while problem-solving skills have an average score of 77.73. Both values fall within the high category, indicating that this application can help students understand abstract material more concretely, as well as train them in analyzing and solving problems related to plant anatomical structures. Thus, the AR Cell and Tissue application deserves to be used as an innovative learning medium in biology education because it not only improves the effectiveness and quality of learning but also supports the mastery of 21st-century skills such as critical thinking, creativity, and problem-solving.

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Authors contributions

Ahmad Bashri, S.Pd., M.Si. was responsible for the conceptualization, methodology, study design, and revision. Prof. Dr. Endang Susantini, M.Pd. and Prof. Dr. Yuni Sri Rahayu, M.Si. contributed to the development of the study design and research instruments. Rinaldiyanti Rukmana, M.Pd. was responsible for data collection and data analysis. Dr. Sifak Indana, M.Pd. reviewed the data analysis. Dr. Ulfi Faizah, S.Pd., M.Si. drafted the initial manuscript, and Muhammad Zahrudin Afnan, S.Pd. conducted the final revision of the manuscript. All authors have read and approved the final version of the manuscript. There were no special agreements regarding authorship, and the contributions of each author have been proportionally acknowledged based on their involvement in the study.

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