



Development of E-Learning Materials Assisted by Augmented Reality in the Science Subject of Changing Energy Forms to Improve Learning Outcomes of Elementary School Students

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Abstract: This study aimed to develop and evaluate the feasibility, practicality, and effectiveness of augmented reality (AR)-based e-learning materials to enhance student learning outcomes. Employing a Research and Development (R&D) approach using the Borg and Gall model, the study involved students from Podorejo 02 Elementary School. Feasibility was assessed through expert validation, which indicated the e-learning materials were "very feasible." Practicality was determined through teacher and student questionnaires, revealing "very positive" satisfaction levels. Effectiveness was demonstrated via a t-test, yielding a significant result ($p < 0.05$) and a moderate N-gain. The findings confirm that AR-based e-learning materials are feasible, practical, and effective in improving science learning outcomes for elementary school students.

Keywords: Augmented reality; Changing the form of energy; E-teaching materials; Science

Introduction

Quality learning, which actively involves students in an interactive and challenging learning process, is the key to producing graduates who are ready to face the challenges of the times (Ang et al., 2021). Education is a journey to develop one's potential, enrich one's insight, and prepare future generations (Grassini, 2023; Kohl et al., 2022; Yu, 2024). This statement is in line with Permendikbudristek No. 12 of 2024 that the Independent Curriculum, with its flexibility and focus on essential materials, provides a strong framework for creating a learning environment that supports students in developing their potential to the fullest. The curriculum is a learning guideline that is always adjusted to the needs of the times and national goals (Anggraini et al., 2022; Suratno et al., 2022).

Permendikbudristek No. 16 of 2022 concerning Standards for Elementary and Secondary Education Processes emphasizes that learning must be interactive

and encourage student activity. Teachers are expected to create a learning atmosphere that involves two-way communication and makes students active subjects in the learning process through a student-centered approach (student-centered learning). Learning is designed to encourage students to think critically, creatively, and exploratively through various methods, such as group discussions, collaborative projects, experiments, and the use of technology. In addition, teachers act as facilitators to ensure an inclusive, positive, and supportive learning environment, so that students feel motivated and actively involved in learning activities. This aims to improve the quality of education by making students the main actors in the learning process. The use of information and communication technology (ICT)-based learning media is currently also an urgent need in the world of education. Therefore, its use must be accompanied by the provision of adequate ICT facilities. In this digital era, the integration of ICT in the learning process in

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schools has become an important part of supporting the creation of effective and optimal learning (Akram et al., 2022; Sailer et al., 2021).

The benefits of ICT-based learning media for students include: enabling independent learning, flexibility in time and place of learning, increasing students' activity and creativity in thinking, and expanding their knowledge. Meanwhile, for educators, the benefits include: educators are no longer the only source of learning because of the abundance of information from ICT, helping to strengthen and motivate the learning process, supporting interaction between educators and students, and organizing learning more effectively. In reality, ideal learning is still difficult to achieve. Teachers tend to use a learning process that is dominated by teachers or Teacher Center Learning (TCL). In TCL, teachers have full control over the learning process. Students only act as listeners. In order for learning to be more effective, teachers need to change their approach and actively involve students (Firmansyah & Jiwandono, 2022). Teachers and students often face various obstacles, such as limited learning resources and challenges in adapting new technologies.

The advancement of digital technology itself has had a major influence on various aspects of life (Salabi, 2022). Technology makes a big contribution to the learning process. Rapid technological developments create golden opportunities for innovation in learning. However, many students who have smartphones rarely use them for learning. This shows that the great potential of technology in education has not been utilized optimally. Based on the various obstacles found, the researcher also identified similar problems in SD Negeri Podorejo 02. Through interviews, questionnaires, observations, grade lists, and documentation of grade IV, several problems were found in the learning process. The results of the questionnaire from 21 grade IV students showed that the subject of science was less popular. Only 3 students (14.28%) liked the subject of science, compared to 5 students (23.80%) who liked mathematics, 6 students (28.57%) who liked physical education, 3 students (14.28%) who liked civics, and 4 students (19.07%) who liked other subjects. Specifically for the material on changing the form of energy, as many as 50% of students admitted that they did not like this material, with the reasons being difficult to understand (35%), too much theory or memorization (20%), not interesting (26%), and other reasons (10%). From the results of the questionnaire, it can be concluded that students' interest in science lessons, especially in the material on changing forms of energy, is still low (Toli & Kallery, 2021).

Researchers found various problems that occurred. Among them are teachers who still use conventional

teaching methods, namely lectures, discussions, questions and answers and demonstrations (Farizi et al., 2019). This is what sometimes makes students bored and learning is less than optimal, which makes students less able to understand the material taught by the teacher. The learning resources used in learning are less varied, namely only using textbooks. The textbooks used are books from the government including teacher books, student books or what are often called LKS. In teacher books and student books, the scope of the material is not broad enough. So teachers must be able to develop the material being taught and students also need to search and dig deeper into the material being taught (Darling-Hammond et al., 2024; Katawazai, 2021). Sometimes the use of textbooks alone does not visualize the material being taught properly. In addition, the use of textbooks, and other learning resources used, namely the surrounding environment that can be used such as in the material on changing forms of energy. In addition, schools have not optimized the use of learning resources assisted by IT. Schools already have a wifi network, but teachers do not utilize these facilities in the classroom. The use of IT-assisted learning resources can actually make learning more varied, interesting and can visualize the material being taught appropriately.

Based on the results of the questionnaire, all students (100%) have smartphones that can be used to access the internet, and 27 students are able to operate smartphones well. However, some students do not utilize smartphones optimally. Only 1 student uses a smartphone to search for additional material, while 8 students use it to play games, 6 students to watch TikTok, 7 students for social media, and 5 students to watch YouTube. However, the questionnaire data shows that some students like the use of smartphones to support learning materials. In addition, support is also given by parents, where 13 out of 16 parents (81.25%) who have filled out the questionnaire agree to the use of smartphones at school with teacher supervision. However, the data shows that so far the use of smartphones by students is still more limited to communication and entertainment needs. Various problems were found in science learning, ranging from the lack of variety of learning resources to the teacher's learning methods which still tend to be traditional. The use of technology-based learning resources is also not optimal, although many students have smartphones that are more often used for playing. Based on data on learning outcomes of grade IV students at Podorejo 02 Elementary School, science learning achievement is still low. Of the total 27 students (8 boys and 19 girls), 15 students (55%) have not reached the KKTP, while 12 students (45%) have met the KKM, with the KKTP set at 76.

In addition, to improve the quality of learning, a variety of learning resources are needed other than textbooks. One way is to develop digital teaching materials. Digital teaching materials are learning materials that utilize electronic technology to present information in a more attractive format, such as video and animation. Digital teaching materials can be very useful for science subjects, especially in explaining abstract concepts that are difficult to visualize. Digital teaching materials or e-teaching materials, including e-books, are designed to provide learning flexibility for students. By utilizing technology, these teaching materials combine various multimedia elements such as images, sound, and video so that they are more interactive and attractive. The main advantage of these e-teaching materials lies in their ability to deliver material in a more attractive way, support a variety of activities, and provide a more interactive learning experience through the use of visualization (Mu'afiqoh & Wachidah, 2024).

The application of a technology-based science learning approach with an emphasis on visualization has proven to be more effective in increasing students' learning motivation and conceptual understanding compared to conventional methods. In this context, Augmented Reality (AR) technology has emerged as a promising innovation to enrich students' learning experiences (Prasetya et al., 2024). Augmented reality (AR) is a technology that creates interactive experiences by combining digital elements into the user's view of the real world. With this technology, concepts that are difficult to visualize traditionally can be presented in a more realistic and interactive way. Augmented Reality offers great potential in improving the quality of science learning at the elementary school level, especially in the context of changing energy forms. Interactive three-dimensional visualizations allow students to gain a deeper and more meaningful understanding. Research shows that current science learning is still lacking in variety and does not actively involve students. In this context, Augmented Reality (AR) technology emerges as a promising innovation to enrich students' learning experiences (Zhao et al., 2023). Augmented Reality (AR) is a technological innovation that presents a new dimension in human interaction with the surrounding environment.

Digital teaching materials equipped with AR provide a more interactive and effective learning experience, especially for difficult science materials. AR not only makes students more active in learning, but also improves conceptual understanding (Al-Ansi et al., 2023). In addition, Augmented Reality also plays an important role in developing students' high-level thinking skills. Practical and easy-to-use AR-based e-

teaching materials further facilitate the learning process. Based on the problems that occur, it was identified that in the learning process, teachers still rarely use variations of IT-assisted teaching materials and lack visualization of science and science material (Abdulrahman et al., 2020). This causes learning to be less interesting and interactive, and it is difficult for students to understand abstract concepts. In addition, learning that is still centered on the teacher also limits student involvement in the learning process. As a result, students tend to be passive and less motivated to learn. In this context, Augmented Reality (AR) technology emerges as a promising innovation to enrich students' learning experiences.

The new media that researchers have developed is Augmented Reality-assisted teaching materials. This Augmented Reality-based teaching material offers an innovative learning experience. Through the integration of AR technology, science learning materials, especially about energy changes, are presented in an interactive 3D visualization format. By scanning the barcode on the book using a mobile device, students can access a more flexible 3D model. Features such as magnification, 360-degree rotation, and video playback allow students to explore complex concepts in depth (Wahyu et al., 2020). For example, the event of energy transformation which is usually only presented in the form of 2D images and descriptions in student books, in this e-teaching material is visualized using Augmented Reality (AR) in 3D. This visualization is equipped with animations that show the change of electrical energy into kinetic energy and light, which are relevant to everyday life. This AR media not only makes learning more interesting and interactive, but also provides a deeper and more comprehensive learning experience.

Based on these various backgrounds, researchers conducted research on the development of e-teaching materials assisted by Augmented Reality to improve the learning outcomes of grade IV students in the Science subject at SD Negeri Podorejo 02. The purpose of this study was to test the feasibility, practicality and effectiveness of the products developed. It is expected that this learning media can make it easier for students to learn grade IV elementary school material.

Method

The type of research used is Research and Development (R&D) research which will produce open e-materials assisted by augmented reality about changing the form of energy. Research and Development (R&D) in the field of learning is a scientific process that aims to create innovation in the form of learning products (Lee et al., 2017). Through a structured

process, this research produces new learning aids that have been tested for their effectiveness. The stages of this research are closely related, in accordance with the characteristics of R&D research. Starting from finding obstacles in the learning culture, then designing innovations in the form of AR e-Learning Materials as a solution. After that, this innovation was tested to see its level of success. The results of this trial are used as a reference for making improvements in the next stage. The focus of this research is the development of Augmented Reality-assisted e-learning materials for the subject of Science with the topic of changing the form of energy in grade IV of elementary school. The development model used is the Borg and Gall model, which consists of 10 steps. However, in this study, the researcher limited the development to the 8th step due to time and cost constraints. An overview of this research scheme can be seen in Figure 1.

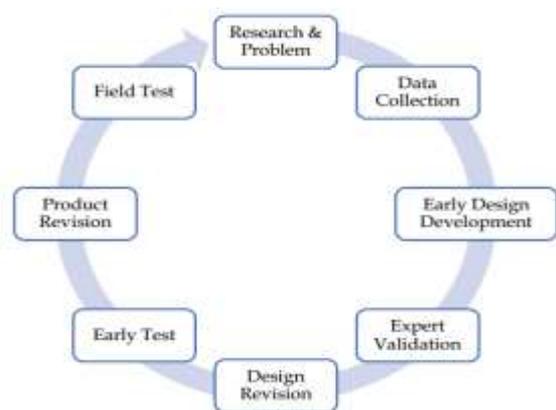


Figure 1. Modified from the Borg and Gall Model

This study began by identifying learning problems in schools. Researchers collected data through observation, interviews, and questionnaires to determine the needs of teachers and students. Based on these data, learning products were designed in accordance with the curriculum. The planning of this product was adjusted to the Learning Outcomes (CP) and Learning Objectives (TP) in the material on changing the form of energy in the subject of science for grade IV Elementary School Phase B. The focus of learning includes the definition of energy, energy sources, types of energy, changes in the form of energy, and problem solving. This product was then assessed by material experts, language experts, and media experts before being used. The experts filled out the validation assessment sheet prepared by the researcher using the Likert Scale format 1-4.

The next stage was to improve the product design based on the suggestions of the experts. The refined product was then tested on a small scale involving 12 grade IV students of Podorejo 02 Elementary School in

the 2023/2024 academic year using the purposive sampling method based on variations in their cognitive ability levels as an initial experiment. At the product trial stage, learning was implemented with the Problem Based Learning (PBL) model and using augmented reality-assisted teaching materials for the material on changing energy forms. After getting feedback from teachers and students, the product was further improved. The final trial was conducted on a large-scale group, involving 20 fourth-grade students of Podorejo 02 Elementary School in the 2024/2025 academic year to measure the extent to which this product was effective in helping students achieve the expected learning objectives.

The data used in this study is original data obtained directly from the source. This data consists of two types, namely data in the form of words (qualitative) and data in the form of numbers (quantitative). Qualitative data was obtained through direct observation, conversations with teachers, and distributing questionnaires to students. Meanwhile, quantitative data was obtained from student test scores and test results before and after treatment was given. To determine the effect of the treatment, the researcher used a one-group pretest-posttest design model by comparing student learning outcomes before and after treatment was given. The difference in student learning outcomes before and after being given treatment is an indicator of the success of the study. In this study, the researcher used a combination of test and non-test techniques. The test used was 32 multiple-choice questions that were the same to measure abilities before and after learning. All questions have been tested for validity using SPSS software. The results of the item analysis are presented in table 1.

Table 1. Recapitulation of Item Analysis Results

Analysis Criteria	Analysis Results
Question Validity	All 32 questions are valid with correlation coefficient values > 0.497
Question Reliability	Cronbach's Alpha Coefficient = 0.95
Difficulty Level	20 questions: Easy Category 10 questions: Moderate Category

While non-test techniques include the results of interviews, questionnaires, observations, grade lists, and documentation. In addition, we also collect data through interviews, questionnaires, observations, grade records, and documents. The assessment of e-teaching materials is carried out comprehensively. The first stage is validation by experts to ensure the suitability of its quality. The validation process is carried out by lecturers at Semarang State University according to competence. Then, to assess the level of practicality of e-teaching materials based on feedback from teachers and students. Finally, data analysis to measure the effectiveness of e-

teaching materials in improving student learning outcomes using statistical analysis. The analysis used is the normality test using Shapiro-Wilk through SPSS software, Paired Samples Test (t-test) and N-Gain test to obtain statistically significant research results.

Result and Discussion

Potential and Problems

Based on initial observations, there are several challenges in science learning at the school. Students are less enthusiastic about science lessons, especially material on changes in energy forms. The existing learning resources are considered less interesting and do not suit the needs of students. Teachers rely more on government books, such as teacher books and student books, as the main source, and occasionally use materials from YouTube without making modifications according to the needs and characteristics of students. In addition, teachers have not utilized the available technological facilities optimally, even though each class is equipped with a Wi-Fi network. This has an impact on the learning outcomes of students studying the Science subject on changing energy forms for grade IV at Podorejo 02 Elementary School in the 2023/2024 academic year, which are quite low.

Data Collection

The initial stage of this study involved interviews with teachers and students filling out questionnaires. The results showed that learning in the classroom was still dominated by the lecture method. This is what sometimes makes students bored and learning is less than optimal, which makes students less able to understand the material taught by the teacher. The learning resources used are also limited and less interesting. The textbooks used are books from the government, including teacher books, student books or often referred to as LKS. The teacher's book and student's book cover less extensive material. In addition, students have access to smartphones but their use is not optimal for learning purposes. The school already has a wifi network, but teachers do not utilize the facility in the classroom. The use of IT-assisted learning resources can actually make learning more varied, interesting and can visualize the material taught appropriately. Many students use their cellphones more often to play games or social media. In addition, schools have not optimized the use of IT-assisted learning resources. The school already has a wifi network, but teachers do not utilize the facility in the classroom. The use of IT-assisted learning resources can actually make learning more varied, interesting and can visualize the material taught appropriately.

Conventional teaching materials have several weaknesses, such as being easily damaged, material that tends to be monotonous, requiring space to carry, and being less attractive to students. This condition makes teaching materials an aspect that needs more attention. On the other hand, the great potential of using smartphones in learning has not been fully utilized by teachers. Based on the results of the questionnaire, 27 students (100%) already have a cellphone that can be used to access the internet. Of the 27 students, they can operate the cellphone well. However, most students use it more often for other things (75.32%). When viewed from the questionnaire data, some students like to use cellphones to support learning materials. In addition, support for the use of smartphones in learning also comes from parents, where 81.25% of them agree to the use of smartphones at school on the condition that they are still supervised by teachers. These data show that there needs to be a strategic step to maximize the potential of smartphones as an effective learning medium in schools. Therefore, the development of digital teaching materials that are integrated with technology is a solution to overcome these shortcomings. Digital teaching materials allow teachers to access them easily, present more interesting materials, and provide a different learning experience for students.

Product Design

This interactive e-learning material is specifically designed to help elementary school students understand the concept of energy change. The material presented is packaged in an attractive and easy-to-understand form, such as images, animations, and 3D objects that can be viewed in three dimensions. The manufacturing process involves several stages, starting from material planning to design development using the Canva and Assemblr Edu applications. The final stage is to combine e-learning materials with augmented reality exported in the form of barcodes, perfecting the design using the Canva application. The final product of this learning media is a digital book that can be accessed online, and can be scanned using the Assemblr Edu application or website, Google Lens, or the default scanner application on a smartphone. The parts of this Augmented Reality-assisted e-learning material consist of the following components:



Figure 2. Front cover

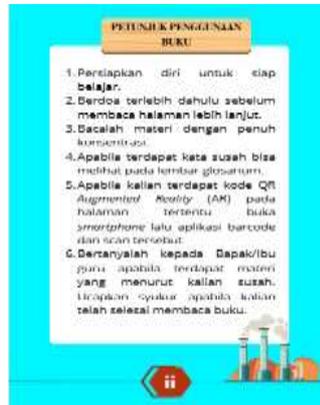


Figure 3. Product instructions for use



Figure 9. Augmented reality changes in energy form



Figure 4. Concept map of all material



Figure 5. CP dan TP



Figure 10. LKPD



Figure 11. Back cover



Figure 6. Material page 1



Figure 7. Material page 2

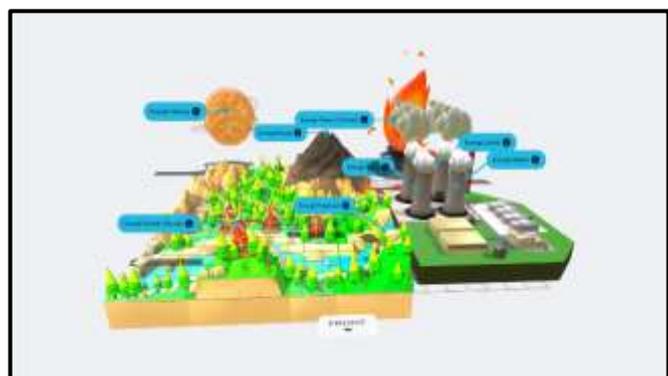


Figure 8. Augmented reality energy sources

The product design stages include preparation of materials; creation of 3D images using Assemblr Edu; and creation of teaching materials and application of Augmented Reality barcodes to teaching materials.

Validation of Augmented Reality-Assisted Teaching Material Product Design

The next stage is to validate the product by involving experts. These experts will evaluate whether the product we have created is in accordance with the needs and standards that have been set. Based on the assessment results, the product will be categorized into several levels of eligibility. Learning media is categorized as very feasible if it gets a score between 82% - 100%, feasible if the score is in the range of 63% - 81%, quite feasible if it gets a score of 44% - 62%, less feasible with a score of 25% - 43%, and very unfeasible if the score is less than 25%. The results of the product validation recapitulation for each expert validator can be seen in Table 2.

Table 2. Results of Expert Validator Assessment of Augmented Reality-Assisted E-Teaching Materials

Indicator	Language Validator	Material Validator	Media Validator
Total Score	48	65	70
Maximum score	52	76	80

Indicator	Language Validator	Material Validator	Media Validator
Percentage	92.30%	85.52%	87.50%
Criteria	Very worth it	Very worth it	Very worth it

The results of validation by experts (Table 2) show that the AR e-teaching materials meet the criteria for excellent eligibility in all aspects, namely material (85.52%), language (92.30%), and media (87.50%). Based on these results, it can be concluded that the AR e-teaching materials have met the requirements for testing.

Design Revision

Based on input from experts in the fields of language, material, and media, the product design has been improved. Input from material experts includes adding explanations about the concept of energy, practice questions, and adjusting images. Linguists improve the use of language according to PUEBI, layout, and punctuation. Meanwhile, media experts suggest changing the color to improve reading comfort.



Figure 16. Energy changes



Figure 17. Energy changes

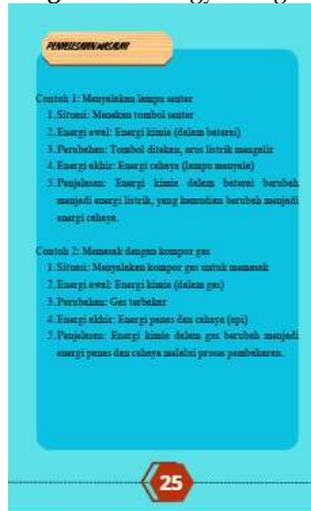


Figure 18. There is no problem solving orientation yet



Figure 19. There is already a problem solving orientation



Figure 12. Definition of too little energy



Figure 13. Complete definition of energy



Figure 14. Energy source is not yet specific



Figure 15. The energy source is specific



Figure 20. Use of introductory words



Figure 21. Substitution for foreword



Figure 22. There are no chapters or sub-chapters yet



Figure 23. There are chapters and subchapters



Figure 24. The colors almost blend together making the writing difficult to read



Figure 25. The color has been changed so that the text can be read clearly

Practicality of Augmented Reality-Assisted Teaching Materials (Product Trial)

The next stage is to conduct a limited trial on the product that has been developed. A total of 12 fourth-grade students of Podorejo 02 Elementary School for the 2023/2024 Academic Year, selected based on the diversity of their cognitive levels, will be the subjects of the trial. After the learning process using e-teaching materials, both teachers and students provide assessments through a response questionnaire. The questionnaire using a Likert scale of 1-4 will be evaluated to determine the level of practicality of the product. The results of this questionnaire will be categorized as very feasible if they get a score between 82% - 100%, feasible if the score is in the range of 63% - 81%, quite feasible if they get a score of 44% - 62%, less feasible if the score is between 25% - 43%, and very unfeasible if the score is less than 25%. The results of the

recapitulation of the expert assessment of the product are presented in detail in Table 3.

Table 3. Results of the Response Questionnaire Teachers and Students on the Use of E-Learning Materials Assisted by Augmented Reality Small-Scale Trial

Respondent	Percentage (%)	Eligibility Criteria
Teacher	98.95	Very Positive
Students	100	Very Positive

Data analysis in Table 3 shows that e-learning materials assisted by Augmented Reality are considered very positive by teachers and students in all aspects evaluated. These very satisfying results indicate that the e-learning materials have great potential to be widely applied in learning activities. Based on the average score on the Likert questionnaire, it can be concluded that this e-learning material is very positive and practical to use.

Table 4. Results of the Teacher and Student Response Questionnaire on the Use of E-Learning Materials Assisted by Augmented Reality Large-Scale Trial

Respondent	Percentage (%)	Eligibility Criteria
Teacher	94.79	Very Positive
Students	96.21	Very Positive

Data analysis in Table 4 shows that both teachers and students gave positive responses to the use of Augmented Reality-assisted e-learning materials. Based on 20 questionnaire questions using a Likert scale of 1-4, this e-learning material is considered very practical. With an average score above 82%, this indicates that AR e-learning materials can be widely applied in the learning process.

Effectiveness of Augmented Reality-Assisted E-Learning Materials

At this stage, a small-scale trial was conducted on grade IV students of Podorejo 02 Elementary School in the 2023/2024 academic year with a total of 12 students using Augmented Reality-assisted e-learning materials in the Science subject on changing energy forms to determine the effectiveness of the product developed by researchers based on student learning outcomes. The research design used was a pre-experimental design with a one-group pretest-posttest design model, namely there was a pretest before treatment was given and a posttest after treatment was given.

Table 5. Results of Pretest and Posttest of Students in Small-Scale Trials

Test Type	Average (%)	Average Difference (%)
Pretest	45.75	32.50
Posttest	78.25	

Quantitative data analysis in Table 5 shows a significant difference between student learning outcomes before and after being given treatment using AR-assisted e-learning materials. An average increase of 32.4% indicates that the use of AR e-learning materials is effective in improving student understanding of the material on changing energy forms. Furthermore, a large-scale trial was conducted on 27 fourth-grade students of Podorejo 02 Elementary School using Augmented Reality-assisted e-learning materials on the material on changing energy forms in the subject of science. This study adopted a pre-experimental research design with a one-group pretest-posttest design model to measure the increase in student learning outcomes after being given treatment.

Based on the data presented in Table 6, it can be concluded that there is an average increase in learning outcomes of 16.30% in students who take part in learning using augmented reality-assisted e-learning materials in the subject of science, material on changing the form of energy. Further data analysis was carried out using the Paired Sample Test (T-Test) to test the difference in the average learning outcomes of students before and after being given treatment using AR e-learning materials. Before conducting the T-test, a normality test was first carried out to ensure that the data was normally distributed. The results of this normality test are presented in Table 6.

Table 6. Results of the Pretest and Posttest of Students in the Large-Scale Trial

Test Type	Average (%)	Average Difference (%)
Pretest	62.72	16.30
Posttest	79.05	

Table 7. Data Normality Test Results

Normality Test			
	Statistic	Df	Shapiro-Wilk Sig
Pretest score	.927	20	.133
Posttest score	.941	20	.251

Based on the results of the normality test in Table 7, it can be concluded that the research data is normally distributed. Furthermore, a paired t-test was conducted to test the difference in the average learning outcomes of students before and after treatment. If the significance value (two-way) is less than 0.05, then there is a statistically significant difference. The complete results of the T-test are presented in Table 8.

Table 8. Paired Sample Test (T-Test) Results

Paired Sample Test			
Pretest Score- Posttest Score	T-statistic	Degree of freedom	Sig. (2-tails)
	-4.744	19	.000

Based on the results of the paired t-test (Table 8), with a significance value of $0.000 < 0.05$, it can be concluded that there is a very significant difference between the average learning outcomes of students before and after using interactive multimedia. In addition, the analysis of improvements using the N-Gain index (Table 9) also shows a significant increase in student learning outcomes.

Table 9. N-Gain Test Results

Average Difference (%)	N-Gain	Class
16.30	.41	Middle

The results of the N-gain analysis show that AR-assisted e-learning materials are effective in improving student learning outcomes, although the increase is in the moderate category. The average student score increased by 16.30% after using this e-learning material. Based on the data analysis, Augmented Reality-assisted e-learning materials have met all the established criteria, both in terms of feasibility, practicality, and effectiveness in improving the learning outcomes of grade IV students in science learning on the material of changing energy forms. This shows that AR e-learning materials are an effective tool for improving students' understanding of the concept of energy changes. This is supported by several supporting factors. First, Augmented Reality (AR)-assisted e-learning materials are an innovation that has the potential to fundamentally change the way teachers teach and students learn (Kamińska et al., 2023; Wang et al., 2024). By integrating interactive digital elements into learning materials, AR can create a more engaging, effective, and student-centered learning experience, thereby encouraging active involvement and improving conceptual understanding (Hafizhah & Setyasto, 2024; Tom Dieck et al., 2024). AR allows teachers to create a more interactive learning environment. Flexibility is one of the main advantages of AR as a learning medium (Fearn & Hook, 2023; Meccawy, 2023; O'Connor & Mahony, 2023).

AR-assisted e-learning materials can be accessed anytime and anywhere via smartphone, providing high flexibility for students to organize their learning time and place. This allows students to learn according to their own rhythm and learning style, thus increasing motivation and learning effectiveness. Second, the application of AR technology in science learning materials offers a promising new breakthrough in the world of education (De Moraes Rossetto et al., 2023; Jaya Saragih et al., 2020). AR-based e-learning materials provide a fresh and interactive learning experience, different from conventional learning methods (Alzahrani, 2020; Roopa et al., 2020). This technology allows the visualization of abstract concepts in science to

be more concrete and easy to understand. For example, students can change the form of energy in three dimensions through their devices. This not only improves students' understanding of the material, but also motivates and interests them in learning science. AR e-learning materials open up opportunities for deeper and more meaningful learning (Lestari et al., 2023; Mystakidis et al., 2021). Third, one of the main advantages of AR e-learning materials is their ease of use (user-friendly) and ease of integration into classroom learning activities (Alyoussef, 2023; Peikos & Sofianidis, 2024).

Teachers can easily implement AR e-teaching materials in various learning activities, both inside and outside the classroom (Al Shloul et al., 2024; De Jong et al., 2019). In addition, AR e-learning materials provide flexibility and ease of access to learning anytime and anywhere (Carmi, 2024; Singh & Ahmad, 2024). This supports independent learning and allows students to learn according to their own pace and learning style. Thus, AR e-learning materials not only improve the quality of learning in the classroom, but also facilitate personalized and flexible learning, expanding learning opportunities for each student. The results of the study indicate that e-learning materials assisted by Augmented Reality can be used as a learning aid by teachers and students to improve learning outcomes. Based on the results of previous studies, conditions, and problems in the field, researchers have succeeded in developing e-learning materials assisted by Augmented Reality for science learning for grade IV elementary school students. Based on the results of the research and analysis that have been carried out, e-learning materials assisted by Augmented Reality have proven to be feasible, practical, and effective for use in science learning for grade IV elementary school students.

Conclusion

This study shows that Augmented Reality-based e-teaching materials in Natural Sciences (IPA) subjects on energy transformation material have proven to be practical and effective in improving learning outcomes for fourth grade students of Podorejo 02 Elementary School. This is supported by expert validation stating that e-teaching materials are very feasible, as well as positive responses from teachers and students. The effectiveness test showed a significant increase in learning outcomes. These findings imply that Augmented Reality-based e-teaching materials can be an innovative solution in science learning, especially on energy transformation material, with the potential to increase student engagement and understanding. Further research can explore the application of these e-

teaching materials in broader contexts and learning materials..

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L. W. L, contributed to the research, product development, data analysis, and writing of the article. N. S., as a supervisor in research activities until writing the article.

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Conflict of Interest

The author declares that he has no conflict of interest.

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