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ORIGINAL RESEARCH

Augmented Reality (AR)-Based E-Module to Improve High School Students' Understanding of Fluid Concepts and Critical Thinking Skills

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Abstract

The development of digital technology has brought significant changes in the world of education, including in the development of innovative and interactive learning media. One of the challenges in learning physics at the high school level is students' low understanding of complex fluid concepts, especially in Bernoulli's Law and Torricelli's Theorem. This study aims to develop an e-module based on Augmented Reality (AR) technology equipped with LKPD, and analyze its effectiveness in improving students' critical thinking skills. The research method used is Research and Development (R&D) with the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model. The developed e-module presents fluid material content visually and interactively through AR simulations, and integrates elements of science, technology, engineering, and mathematics in the context of physics learning. Implementation was carried out in high schools, with data collection through pre-tests, post-tests, and student and teacher response questionnaires. The results showed that the AR-based e-module equipped with LKPD was suitable for use based on validation by media experts (89%) and material experts (82%), and obtained an increase in critical thinking skills of 0.62 (moderate category) based on the gain test. In conclusion, the development of an AR-integrated e-learning module on the Bernoulli and Torricelli concepts can be an effective innovation to improve students' conceptual understanding and critical thinking skills in physics learning in the digital era.

Keywords: E-modul · *Augmented Reality* · Fluids · Interactive Media · Education Innovation

INTRODUCTION

Rapid technological developments have impacted various aspects of society, including education. One significant change is the increasing use of innovative and interactive learning media (Sari & Azizah, 2023). Learning media are now more engaging and effective without diminishing the essence of the material being delivered. Learning media are anything used to convey messages and stimulate students' thoughts, feelings, attention, and willingness to learn, thereby encouraging a directed and controlled learning process. The use of learning media must be applicable to all subjects, including physics. Learning media must be packaged in an attractive manner to facilitate student learning (Matsun et al., 2019). Education today is required to continue to innovate, not only based on knowledge transfer, but also developing skills such

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as creativity, collaboration, communication, and problem-solving, and most importantly, critical thinking skills, which are increasingly needed in this digital era (Nilyani et al., 2023).

One important topic in physics that students often find difficult to understand is fluids because it is complex and requires a deeper understanding of the relationship between pressure, flow velocity, and fluid energy at various points in the system. Furthermore, this topic is often considered difficult because it involves complex mathematical calculations (Amelia et al., 2023; Dhanil et al., 2024). This indicates the need for learning media that can bridge the gap between theory and practice to improve students' understanding of the material (Qotrunnada et al., 2023; Zaidah & Mahariyanti, 2020).

Understanding complex physics concepts, such as fluids, requires not only the ability to memorize formulas and theories, but also critical thinking skills that involve analyzing, evaluating, and applying theories to real-world situations. Critical thinking skills are essential in physics learning so students can deeply understand and apply the physics concepts they learn, as well as solve problems logically and structuredly. Therefore, Augmented Reality (AR)-based learning media offers a highly relevant solution.

With the advancement of digital technology, Augmented Reality (AR) has emerged as an innovative solution in education (Rebello et al., 2024). AR allows students to visualize difficult-to-understand concepts directly through digital devices, providing a more interactive and immersive learning experience (Putra et al., 2023). In the context of fluids, AR can be used to simulate fluid flow, pressure, or the application of related physical laws, enabling students to more easily understand these phenomena. Although AR has great potential in physics learning, its use in schools remains limited, primarily due to the lack of technology-based interactive learning resources that are easily accessible to teachers and students (Ferdiman et al., 2023; Pujiastuti & Haryadi, 2024).

Furthermore, existing AR-based learning media are still relatively new and have not been fully implemented in the context of physics learning. AR is a technology that adds virtual objects in two or three dimensions to a real, projected environment simultaneously (Hidajat, 2024; Koparan et al., 2023). Learning should be carried out through interactions between teachers and students in a fun, challenging, and motivating learning environment. Therefore, the development of AR-based learning media is a strategic step to improve the quality of physics learning, particularly in fluids (Lyrath et al., 2023; Qiao et al., 2024).

Previous research has applied AR in physics learning, such as that conducted by Kencana et al. (2021), on Augmented Reality Geometrical Optics (AR-GiOs) for optics learning in secondary schools, and research by Isma et al. (2024), on the development of AR-based physics learning media. This research is part of Research and Development (RnD) using 2D and 3D-based research and development models. In addition, the approach used is the ADDIE model consisting of Analysis, Design, Development, Implementation, and Evaluation. The ADDIE model was chosen because of its flexibility in developing learning products that can be applied to models, strategies, methods, media, and teaching materials (Radu et al., 2023).

The novelty of this research lies in the application of specific AR objects tailored to the needs of high school physics materials, particularly fluids. The development of this learning media also utilizes the Unity platform to produce intuitive AR content accessible through devices such as smartphones or tablets, which are already widely used by students (Alhejri et al., 2022). This step is expected to provide a more contextual, interactive, and enjoyable

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learning experience, while also being relevant to technological developments and educational needs in the digital era (Marques et al., 2024; Upadhyay et al., 2024). This research aims to develop Augmented Reality-based learning media for fluids, specifically to improve students' critical thinking skills in high school physics learning. This research will explore the use of AR technology for visualizing complex concepts and measure its impact on students' abilities to identify and solve physics problems related to fluids.

METHOD

Research Design

The research was conducted using a quasi-experimental approach, aiming to develop an AR-based e-learning module on fluid concepts and to test the effectiveness of this medium in improving students' critical thinking skills.
The model used in the development is based on the ADDIE model, which consists of the following five stages, including: 1) Analysis: Identifying learning needs and problems faced by students; 2) Design: Designing the content and structure of AR-based learning media in the form of e-modules equipped with worksheets (LKPD); 3) Development: Developing learning media based on the design; 4) Implementation: Testing learning media in the classroom; and 5) Evaluation: Evaluating the effectiveness of learning media and making revisions based on the test results.

Research Procedures

This research procedure consists of several steps as follows.

Needs Analysis

The first stage was to conduct a needs analysis by collecting data on student conditions and required learning materials. This research began with interviews with physics teachers and observations in 11th-grade classes at Karawang State Senior High School to identify the problems students faced in understanding fluid concepts.

Learning Media Design

After identifying the needs, the next stage is designing an AR-based e-learning module, which includes creating a storyboard, interactive content, and display design. This design ensures that the developed media meets learning objectives, is engaging for students, and is easy to use.

Media Development

In the development stage, the designed learning media is tested in prototype form. This development involves creating AR content that can be accessed through devices such as smartphones or tablets.

Implementation in the Classroom

An AR-based e-learning module equipped with student worksheets (LKPD) was then implemented in class XI students at SMA Negeri 6 Karawang. The implementation involved

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integrating the AR e-module into physics learning activities over several sessions to test its effectiveness and impact on students' critical thinking skills.

Evaluation

Evaluations were conducted to measure students' critical thinking skills using pre- and post-test instruments, as well as student response questionnaires regarding their experiences using the media. Validation tests were conducted with media and content experts to ensure the feasibility and effectiveness of the developed product.

Research Sample

The product trial in this study involved 36 eleventh-grade students at SMA Negeri 6 Karawang. Students were randomly selected as respondents, with classes divided according to the applicable physics curriculum. Sampling was conducted by considering the appropriateness of the material taught and the research objectives.

Data Collection Instruments

The instruments used to collect data in this study include the following steps and stages.

Validation Test by Media Experts

To ensure the feasibility of the design and functionality of the AR-based learning media, a validation test was conducted by media experts. The media experts involved have experience in developing digital learning media and AR. The data collection process for the validation test was carried out by administering a questionnaire containing questions related to effectiveness, efficiency, user satisfaction, and media design. Each aspect was measured using a Likert scale to obtain a quantitative assessment from the media experts. The data obtained from this questionnaire were then analyzed descriptively to determine the media's feasibility based on the scores given by the media experts.

Validation Test by Material Experts

Validation testing by subject matter experts was conducted to ensure that the learning content in the AR media aligns with the established curriculum and learning objectives. The data collection process for material validation involved administering a questionnaire to the subject matter experts, which assessed aspects of content (completeness, accuracy, and relevance), written language, and suitability to the high school physics curriculum. The scores obtained from the subject matter experts were used to assess whether the learning media was scientifically acceptable and aligned with existing educational standards.

Pre-test and Post-test

In addition to validation by media and material experts, pre-tests and post-tests were used to measure changes in students' critical thinking skills before and after using AR-based learning media. Measurement of critical thinking skills focused on three main indicators, namely: (1) analysis, students' ability to analyze information and identify relationships between components; (2) inference, the ability to draw logical conclusions based on available data or information; and (3) evaluation, the ability to assess arguments or decisions based on certain criteria. The test was given in the form of 7 questions based on fluid material, arranged

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according to critical thinking indicators and distributed using Google Forms to facilitate implementation and data collection. Data from the pre-test and post-test were then analyzed using a gain test.

Data Analysis Techniques

Data obtained through validation tests by media experts and material experts were analyzed to assess the product's feasibility. The following provides a further explanation of the analysis process.

Analysis of Media Expert and Material Expert Validation Tests

Validation data from media and content experts was analyzed using percentages of achievement for each measured aspect, such as effectiveness, satisfaction, and media design by media experts, and content and written language by content experts. Percentage scores were calculated using the following formula:

$$\% \text{ Achievement} = \frac{\text{score obtained}}{\text{maximum score}} \times 100 \quad (1)$$

The results of this validation are used to determine whether the learning media is acceptable or needs improvement based on expert advice. Media suitability is determined if the average achievement percentage is above 80%.

Pre-test and Post-test Data Analysis with N-Gain Test

To measure the improvement in students' critical thinking skills, an N-Gain Test analysis was carried out which was calculated using the following formula.

$$N\text{-}Gain = \frac{(Post\text{-}test\ score - Pre\text{-}test\ score)}{(Maximum\ score - Pre\text{-}test\ score)} \quad (2)$$

The N-Gain value indicates the extent to which students' critical thinking skills have improved, with categories ranging from high (N-Gain $\geq$ 0.7), medium (0.3 $\leq$ N-Gain $<$ 0.7), and low (N-Gain $<$ 0.3). Cohen's test is used to measure the statistical significance of changes in scores, ensuring that any differences are not due to chance.

RESULTS AND DISCUSSION

Development Results

The results of product development in the form of an Augmented Reality-based e-module on fluid concept material are shown in Figure 1. This e-module is designed as an interactive learning media that combines text, images, and AR simulations to help students understand fluid concepts in a more concrete and interesting way. The e-module is also equipped with Student Worksheets (LKPD) designed to facilitate students in constructing knowledge independently through observation, exploration, and problem-solving activities. The appearance of the developed LKPD is shown in Figure 2.

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Figure 1. Final view of the e-module on the Fluid concept

Figure 2. Final view of LKPD (Student Worksheet)

After students scan the QR code provided in the e-module, the system displays an AR object that visually and interactively represents the fluid concept. This AR display aims to help students understand fluid phenomena more concretely through engaging and easy-to-use three-dimensional simulations. Figure 3 shows the AR media display that appears after scanning the QR code.

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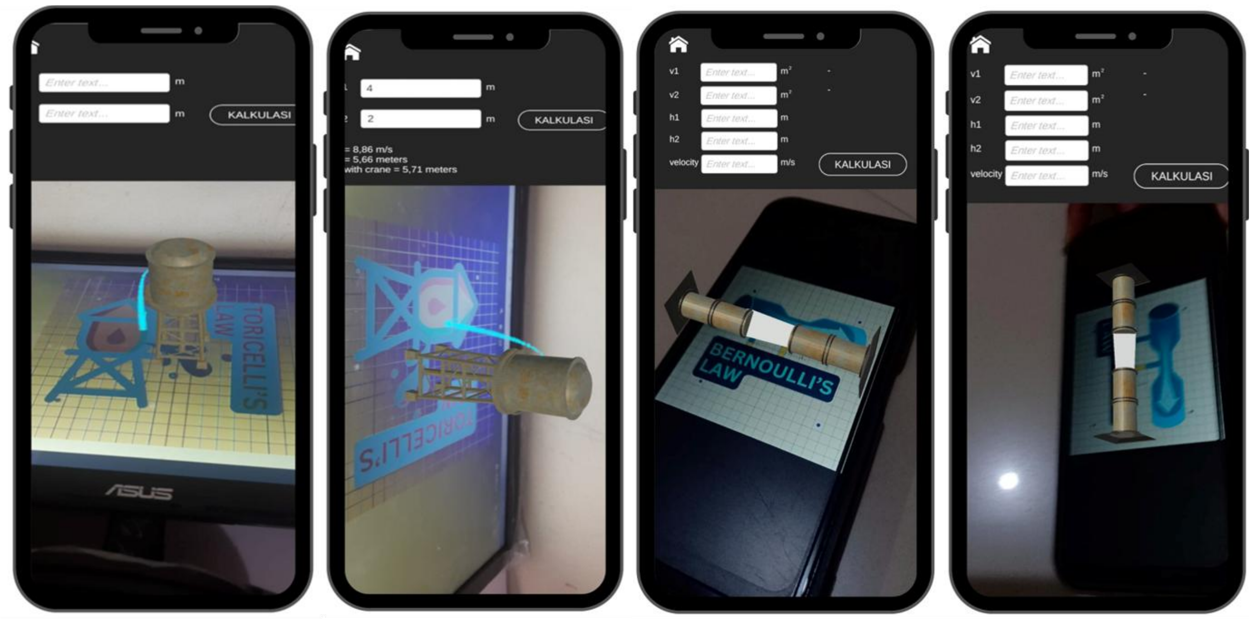

Figure 3. AR media display

Validation Test Results and Critical Thinking Skills

The use of Augmented Reality in physics learning, particularly on fluid concepts, aims to enhance student understanding through interactive visualizations and real-time simulations. In this study, the development of AR-based learning media underwent validation by media and content experts to ensure its quality and effectiveness in supporting learning in high school. The results of the validation test of AR-based learning media by media experts are shown in Table 1.

Table 1. Results of AR-Based Learning Media Validation Test by Media Experts

No.	Aspects measured	% Achievement	Interpretation
1	AR Effectiveness	86%	Very good
2	AR Efficiency	92%	Very good
3	Satisfaction with AR	90%	Very good
4	Student Worksheet Design	85%	Very good
5	Student Worksheet Components	89%	Very good
6	Student Worksheet Content	92%	Very good
Average of all measured aspects		89%	Very good

The validation test results indicate that the AR-based learning media meets the criteria for excellent quality in all measured aspects. The effectiveness and efficiency of the AR media received an excellent rating with an achievement percentage of more than 85%. Satisfaction with the developed AR media also showed excellent results, with a score of 90%, reflecting the positive acceptance of the use of AR in learning by media experts. In addition, the design and content aspects of the Student Worksheets integrated in the AR media also received an excellent rating, with an average score of 89%. This indicates that the designed LKPD is able to support learning well, facilitate students in understanding the material presented, and increase their interaction with physics concepts. In addition to the results of the AR-based learning media validation test by Media Experts, the feasibility of the learning media material was also validated by material experts as presented in Table 2.

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Table 2. Results of the AR Validation Test of the Fluid Concept by Material Experts

No.	Aspects measured	% Achievement	Interpretation
1	Concepts of 3D Objects	84%	Very good
2	Content of the Student Worksheet	82%	Very good
3	Language of the Student Worksheet	80%	Good
Average of all measured aspects		82%	Very good

The validation test results by subject matter experts indicated that the content presented in the AR-based learning media aligned with the curriculum and significantly supported students' understanding of fluid concepts. The concepts presented in 3D objects received a very good rating with a score of 84%, indicating that the visualizations used were able to clearly and accurately depict fluid phenomena. The content of the Student Worksheet also received a very good rating, with a score of 82%, indicating that the information presented in the LKPD was easy to understand and relevant to the learning process. However, the written language aspect received a score of 80%, indicating that although the language used was quite good, there were still several areas for improvement to further facilitate student understanding.

Following the validation test, testing was conducted to determine the effectiveness of the AR-integrated e-module learning media on students' critical thinking skills. The learning activities involved administering pretests and posttests. After the pretest, calculations were conducted to determine students' critical thinking skill levels in the analysis, inference, and evaluation indicators. Table 3 below shows the results of the student pretest based on data from the assessment rubric administered prior to the learning process, with a total of 36 students.

Table 3. Students' Critical Thinking Skills Level Based on Pretest (N=36)

Score	Criteria	Frequency	Percentage
71,50 – 81,25	High	-	-
62,50 – 71,50	Moderate	3	8,33%
43,75 – 62,50	Low	8	22,22%
0 – 43,75	Very Low	25	69,45%
Total		36	100%
Average Score		42,18	

Based on Table 3, the level of critical thinking skills in the analysis, inference, and evaluation indicators based on the pretest results shows that the majority of students scored below 43.75, falling into the Very Low category (25 out of 36 students (69.45%). Eight students (22.22%) fell into the Low category, with a score range of 43.75–62.5, and three students (8.33%) fell into the Moderate category, with a score range of 62.5–71.5. The average score for the KBK test based on the pretest was 42.18 out of a total score of 100, falling into the Very Low category.

To calculate the increase in scores after using the AR-integrated e-module as a learning medium, a posttest was conducted to determine the increase in KBK after the learning process. The posttest scores are shown in Table 4.

Table 4. Students' Critical Thinking Skills Level Based on Post-Test (N=36)

Score	Criteria	Frequency	Percentage
71,50 – 81,25	High	28	77,78%
62,50 – 71,50	Moderate	8	22,22%
43,75 – 62,50	Low	-	-

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Score	Criteria	Frequency	Percentage
0 – 43,75	Very Low	-	-
Total		36	100%
Average Score		77,71	

After students participated in learning using AR-integrated e-module learning media on fluid material, a post-test was conducted to measure the development of critical thinking skills. The post-test results showed a significant increase compared to the previous pre-test results. Based on the data in Table 4, 28 students (77.78%) obtained scores in the High category, with a score range of 71.50 - 81.25. Meanwhile, 8 students (22.22%) were in the Moderate category. There were no students in the Low or Very Low categories, indicating that all students experienced an increase in critical thinking skills towards the better. The overall average score obtained by students in the post-test was 77.71 out of a total score of 100, which is included in the high category. This achievement indicates that the majority of students have demonstrated good abilities in analyzing information, drawing logical conclusions, and critically evaluating arguments or decisions. Next, the Gain Test calculation is obtained based on the results of the pre-test and post-test which are then calculated to obtain the values as in Table 5.

Tabel 5. Hasil Uji Gain

Bentuk Tes	Nilai Rata-rata	Nilai Uji Gain
Pretes	42,18	0,62
Postes	77,71	

Berdasarkan hasil uji gain pada Tabel 5, diperoleh nilai rata-rata pretes sebesar 42,18 dan postes sebesar 77,71 dari total nilai 100. Perhitungan nilai gain ternormalisasi (N-gain) menunjukkan skor sebesar 0,62, yang berada dalam kategori sedang hingga tinggi. Hasil ini mengindikasikan bahwa penggunaan e-modul terintegrasi AR efektif dalam meningkatkan keterampilan berpikir kritis siswa pada materi fluida.

Pembahasan

Berdasarkan hasil validasi oleh ahli media, aspek desain, tampilan, dan fungsionalitas aplikasi mendapatkan penilaian sangat baik dengan rata-rata skor 89%. Hal ini menunjukkan bahwa media pembelajaran berbasis AR telah memenuhi standar yang baik dalam kemudahan penggunaan dan interaktivitas. Visualisasi tiga dimensi yang disediakan dalam aplikasi ini juga dinilai efektif dalam membantu siswa memahami fenomena fluida secara lebih nyata. Penggunaan visualisasi interaktif sejalan dengan teori konstruktivisme yang mengemukakan bahwa pemahaman konsep-konsep ilmiah dapat ditingkatkan ketika siswa terlibat secara aktif dalam proses belajar melalui pengalaman langsung (Piaget, 1976). Dalam konteks ini, AR memungkinkan siswa untuk mengamati dan berinteraksi dengan objek tiga dimensi yang menggambarkan konsep fluida, sehingga memberikan pengalaman belajar yang lebih konkret dan memperkuat pemahaman mereka terhadap materi secara lebih mendalam.

Sementara itu validasi oleh ahli materi menghasilkan skor rata-rata 82% yang juga tergolong dalam kategori sangat baik. Penilaian ini mencakup kesesuaian isi materi dengan kurikulum, keakuratan konsep fisika yang disajikan, serta relevansi simulasi dengan fenomena nyata. Hasil ini menunjukkan bahwa penggunaan teknologi multimedia seperti AR dapat memperkaya pengalaman belajar dengan menghubungkan teori dengan aplikasi praktis.

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Konsep-konsep yang diajarkan dalam media AR ini juga dapat mengatasi tantangan dalam pembelajaran fisika seperti tekanan dan aliran fluida, yang sulit digambarkan hanya dengan teks dan gambar statis. Oleh karena itu, simulasi berbasis AR ini mendukung pemahaman yang lebih dalam dengan memberikan pengalaman belajar yang dinamis dan interaktif.

Aplikasi AR ini telah memenuhi kriteria kelayakan sebagai media pembelajaran yang dapat digunakan untuk mendukung pemahaman konsep fluida secara lebih mendalam. Sejalan dengan penelitian sebelumnya oleh Freeman et al. (2014), yang mengemukakan bahwa penggunaan teknologi interaktif dalam pembelajaran dapat meningkatkan keterlibatan dan motivasi siswa, temuan dalam penelitian ini juga menunjukkan bahwa siswa lebih tertarik dan termotivasi untuk belajar fisika ketika media pembelajaran didukung dengan teknologi yang menarik dan interaktif.

Selain hasil validasi, implementasi media AR dalam pembelajaran fisika memberikan beberapa keuntungan signifikan. Siswa dapat berinteraksi langsung dengan konsep fluida melalui simulasi yang dapat diakses secara mandiri menggunakan perangkat digital. Hal ini meningkatkan keterlibatan aktif dalam proses pembelajaran, mengurangi kesulitan dalam memahami materi yang kompleks, serta mendorong keterampilan berpikir kritis dan eksploratif. Pembelajaran berbasis teknologi seperti ini juga mendukung teori pembelajaran sosial Vygotsky (1978), yang menekankan pentingnya interaksi sosial dan kolaborasi dalam pembelajaran. Dengan adanya fitur interaktif dalam media AR, siswa dapat lebih mudah berdiskusi dan bekerja sama dalam memahami konsep-konsep yang diajarkan.

Berdasarkan hasil uji validasi dan data yang diperoleh dari pretes dan postes, penggunaan e-modul berbasis Augmented Reality (AR) terbukti efektif dalam meningkatkan keterampilan berpikir kritis siswa pada materi konsep fluida. Pada tahap pretes, yang dilakukan sebelum pelaksanaan pembelajaran, mayoritas peserta didik berada pada level keterampilan berpikir kritis yang sangat rendah (*Very Low*) dengan nilai rata-rata 42,18. Hasil ini menunjukkan bahwa sebelum menggunakan media pembelajaran berbasis AR, siswa mengalami kesulitan dalam menganalisis, menarik kesimpulan, dan mengevaluasi informasi yang berkaitan dengan konsep fluida.

Namun, setelah mengikuti pembelajaran menggunakan e-modul berbasis AR, hasil postes menunjukkan peningkatan yang signifikan pada keterampilan berpikir kritis siswa. Sebanyak 77,78% siswa memperoleh skor dalam kategori *High*, dengan nilai rata-rata 77,71, yang menunjukkan peningkatan kemampuan berpikir kritis yang sangat baik. Tidak ada siswa yang kembali masuk ke dalam kategori *Low* atau *Very Low*, yang menunjukkan bahwa seluruh peserta didik mengalami peningkatan dalam keterampilan berpikir kritis mereka. Peningkatan ini membuktikan efektivitas e-modul AR dalam memberikan pengalaman belajar yang mendalam dan interaktif, memungkinkan siswa untuk memahami materi lebih baik melalui simulasi visual yang mendalam dan interaksi langsung dengan konsep-konsep fisika.

Hasil ini konsisten dengan teori konstruktivisme yang mengemukakan bahwa keterampilan berpikir kritis dapat diperoleh lebih baik ketika siswa aktif terlibat dalam pembelajaran yang interaktif dan berbasis pengalaman nyata (Bransford et al., 2000). Melalui media AR, siswa tidak hanya melihat konsep-konsep fisika secara teoritis, tetapi mereka juga dapat mengamati dan berinteraksi langsung dengan fenomena yang terjadi dalam dunia nyata. Lebih lanjut, hasil uji gain dengan nilai 0,62 (kategori sedang hingga tinggi) menunjukkan bahwa penggunaan e-modul berbasis AR tidak hanya memberikan peningkatan keterampilan berpikir kritis yang

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signifikan, tetapi juga mampu menciptakan pembelajaran yang efektif dan efisien. Menurut Hake (1998), nilai N-gain yang berkisar antara 0,3 hingga 0,7 tergolong dalam kategori sedang hingga tinggi, yang mencerminkan bahwa pembelajaran berbasis AR ini telah berhasil meningkatkan pemahaman dan keterampilan siswa secara substansial.

Secara keseluruhan, hasil penelitian ini menunjukkan bahwa e-modul berbasis AR memiliki potensi yang besar untuk meningkatkan keterampilan berpikir kritis siswa, khususnya dalam pembelajaran fisika mengenai konsep fluida. Penggunaan teknologi ini mampu menciptakan pengalaman belajar yang lebih interaktif, menarik, dan menyenangkan, serta memberikan dampak positif terhadap peningkatan kemampuan analisis, evaluasi, dan pengambilan keputusan siswa. Oleh karena itu, e-modul AR ini dapat dijadikan alternatif media pembelajaran yang efektif dan inovatif di tingkat SMA, untuk mendorong siswa dalam mengembangkan keterampilan berpikir kritis yang diperlukan dalam menghadapi tantangan abad ke-21.

KESIMPULAN

Berdasarkan hasil penelitian mengenai penggunaan e-modul berbasis *Augmented Reality* dalam pembelajaran fisika pada materi konsep fluida, dapat disimpulkan bahwa media pembelajaran berbasis AR efektif dalam meningkatkan keterampilan berpikir kritis siswa. Hasil uji validasi menunjukkan bahwa media pembelajaran ini memiliki tingkat kelayakan yang tinggi berdasarkan penilaian ahli media dan ahli materi, dengan persentase rata-rata skor masing-masing 89% dan 82%. Persentase ini menunjukkan bahwa aplikasi AR yang dikembangkan telah memenuhi standar kualitas yang baik dari segi desain media maupun isi materi. Hasil pretes dan postes menunjukkan adanya peningkatan keterampilan berpikir kritis siswa yang signifikan setelah menggunakan media pembelajaran berbasis AR. Sebanyak 77,78% siswa menunjukkan peningkatan yang sangat baik, masuk ke dalam kategori *High* dalam hasil postes. Dengan nilai rata-rata N-gain 0,62, yang tergolong dalam kategori sedang hingga tinggi, hal ini mengindikasikan bahwa penggunaan AR mampu mendorong siswa untuk lebih aktif dalam menganalisis, menarik kesimpulan, dan mengevaluasi informasi.

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