Design and Validation of a Physics Learning Website Based on Cognitive Conflict, AR, and STEM to Support Critical Thinking Skills

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***Abstract*—This study aims to design a physics website based on cognitive conflict, Augmented Reality (AR), and Science, Technology, Engineering, and Mathematics (STEM) that is valid to support students' critical thinking skills. The study employed an Educational Design Research (EDR) approach consisting of three stages: analysis and exploration, design and construction, and evaluation and reflection. The participants included 404 randomly selected upper secondary students in West Sumatra, Indonesia, and six experts for validation. Data were collected through a needs analysis questionnaire and expert validation sheets. The needs analysis was examined using descriptive statistics, t-tests, and ANOVA, while product validity was assessed with Aiken's *V* index. The findings indicate that students across different grade levels, both male and female, share similar perceptions regarding socio-emotional aspects, efficiency, actual behavior, and preferences, underscoring the need for integrating a physics website into the learning process. This study produced a validated physics website (*V* > 0.8) that integrates AR, STEM, and the cognitive conflict-based learning model to support students' critical thinking skills. This design was found to address student needs and was validated as being valid. This study was limited to the design stage; therefore, the developed website is recommended for further testing to evaluate its effectiveness. It has the potential to enhance digital learning by fostering engagement and improving students' critical thinking skills.**

***Keywords*—augmented reality, cognitive conflict, critical thinking skills, Science, Technology, Engineering, and Mathematics (STEM)**

I. Introduction

The development of digital technology has driven a significant transformation in education over the past decade. The integration of technology into learning not only serves as a medium for delivering content but also as a tool to enhance the quality of learning experiences, expand access to information, and foster interactivity between teachers and students [1]. The presence of technology allows learning to become more flexible, innovative, and adaptive to the needs of the 21st century, which demands higher-order thinking skills such as critical thinking, problem-solving, and collaboration [2, 3]. In practice, digital technology can be packaged in the form of applications or websites to support more effective and engaging learning [4, 5]

One prominent form of technology that supports learning innovation is Augmented Reality (AR). AR is a technology that combines the real world with three-dimensional virtual objects, thereby creating a more contextual, realistic, and interactive learning experience [6, 7]. This technology enables students to visualize abstract phenomena in manipulable three-dimensional forms, which facilitates the understanding of complex concepts such as human anatomy [8, 9], natural phenomena [10], and chemical reactions [11, 12]. AR technology has the potential to create an interactive and realistic constructivist learning environment, reflecting the impact of immersive technology in education and supporting the implementation of Science, Technology, Engineering, and Mathematics (STEM) [13]. Although AR holds great potential, its implementation in physics learning remains suboptimal [14, 15] due to various challenges, including the limited availability of media and relevant applications for AR implementation in physics education [16].

These limitations underscore the pressing need to support digitally oriented learning, as physics is characterized by abstract and complex concepts that often lead to misconceptions and require interactive visual media to explain scientific phenomena more concretely. This issue is reflected in students' low levels of critical thinking skills [17, 18]. To address these challenges, it is essential to examine the pedagogical and psychological dimensions that influence students' learning experiences in physics.

Problems in physics learning can arise from various factors, including teaching strategies, approaches, learning models, student characteristics, and students' psychological conditions in implementing technology [19]. Psychological aspects of learning, such as socio-emotional [20], efficiency of use, behavior, and preferences, are important considerations for improving learning quality [21]. Therefore, understanding these perceptual and psychological aspects becomes crucial when designing physics learning environments that integrate advanced technologies such as AR and STEM.

Building on this theoretical foundation, this study bridges the gap between digital learning innovation and learners' psychological needs by analyzing students' initial perceptions, including gender, socio-emotional aspects, efficiency, actual behavior, and preferences, as key variables in designing technology-enhanced physics learning. The innovative solution and novelty offered in this study lie in analyzing students' initial needs based on gender, socio-emotional aspects, efficiency, actual behavior, and

preferences; identifying relevant learning characteristics for students; and designing technology-oriented learning by integrating STEM, a cognitive conflict-based learning model, and AR technology into a website to support critical thinking skills. The STEM approach is selected because it emphasizes viewing concepts from multiple disciplinary perspectives and aims to support critical thinking skills [22, 23]. In addition, the cognitive conflict-based learning model emphasizes inquiry in addressing misconceptions, which remain a primary issue in physics education [24]. Therefore, this study aims to design a physics website based on cognitive conflict, AR, and STEM that is valid to support students' critical thinking skills. To achieve this focus, the study is directed to answer the following research questions:

1) What are the characteristics of learning that integrate a physics website containing AR, a cognitive conflict-based learning model, and STEM in physics instruction to support students' critical thinking skills?
2) What are students' perceptions of AR-assisted physics learning regarding socio-emotional aspects, efficiency, actual behavior, and preferences?
3) How do students' perceptions differ based on gender (male and female)?
4) How do students' perceptions differ based on grade level?
5) What are the outcomes of the framework, the resulting website product, and the validity of the integrative physics website in facilitating students' critical thinking skills?

II. Literature Review

A. Augmented Reality (AR)

AR is a digital technology that enables users to visualize phenomena in three-dimensional space within a real environment [25]. Over the past decade, AR has become a growing trend because of its ability to provide interactive simulations, allowing virtual objects to be rotated, enlarged, and manipulated as if they were real [26, 27]. In the context of learning, this technology facilitates the explanation of everyday phenomena in a simpler and more comprehensible way [28].

Simulation is particularly important in physics learning, as many concepts are abstract and cannot be observed directly. Previous studies have employed images and videos as instructional media [29, 30]; however, two-dimensional representations remain passive and less interactive. AR offers a significant advantage by creating a wider space for students to interact with virtual objects [10].

The implementation of AR-based learning has shown a growing trend that influences various sectors, including industry, business, engineering, and traditional education, by fostering students' curiosity and interactivity in schools [31]. AR technology also supports learning oriented towards the STEM approach, thereby enhancing students' performance and engagement in the learning process [32]. The advantages and increasing trend of AR utilization across educational fields highlight its potential to improve learning quality, particularly in physics education.

Nevertheless, the implementation of AR in physics learning is still limited in several ways: (1) it only covers specific content, (2) it is not yet integrated into a compact platform, and (3) it has not been framed within a coherent instructional design. These gaps highlight the necessity for developing AR applications that are more comprehensive, integrated, and aligned with the objectives of physics education.

B. Science, Technology, Engineering, and Mathematics (STEM)

The STEM approach is designed to solve problems from multiple disciplinary perspectives, thereby generating a holistic understanding. This approach is highly relevant in physics learning because physics is inherently connected to mathematics, technology, and engineering [30]. STEM allows students to grasp scientific concepts and design, construct, and test tools or experiments based on these concepts [33].

The development of technological systems has influenced various aspects of learning, one of which is the application of AR, considered relevant in supporting STEM education [34]. AR technology contributes to improving performance in the learning process and developing STEM-based learning environments [32, 35]. It also serves as an important tool in supporting learning through the STEM approach [36, 37]. Moreover, AR is a rapidly evolving technology that enhances STEM learning through visualization and simulation [38]. Although numerous studies have explored the use of AR in STEM contexts, its application remains limited to simulation media on specific topics, such as magnetism [39], fluids, and atomic structures [40].

Although several previous studies have applied STEM, most have been limited to presenting separate content or isolated activities, without a framework that ensures coherence between subject matter, technology, and students' needs [41]. In fact, integrating media that is consistent with the characteristics of physics learning and responsive to differences in students' backgrounds (e.g., gender) is crucial to avoiding misconceptions and enhancing relevance [42]. In this respect, combining innovative technologies such as AR [43] with a STEM approach is a promising solution [44]. However, prior research remains scarce in developing a framework that unifies AR and STEM in physics education. This highlights a pressing need for in-depth investigations to develop a more comprehensive instructional design.

C. Cognitive Conflict-Based Learning Model

The cognitive conflict-based learning model emphasizes conceptual change and the remediation of misconceptions through stages: activating preconceptions, presenting cognitive conflict, discovery of concepts and equations, and reflection [24]. This model supports the construction of more accurate knowledge and promotes students' higher-order thinking skills [45]. In practice, the cognitive conflict-based learning model can be enriched through videos [29] or other digital media presenting conflicts capable of stimulating deeper reasoning [46].

Several studies have demonstrated that the cognitive conflict-based learning model can reduce misconceptions. However, its application in physics learning still faces notable challenges. First, misconceptions remain prevalent due to students' limited conceptual understanding [47, 48]. Second, few studies have integrated the cognitive

conflict-based learning model with innovative technologies such as AR. Third, there has been no attempt to systematically situate cognitive conflict within a STEM and AR framework, which would render it more contextualized and responsive to students' needs. Therefore, designing a physics learning model that integrates the cognitive conflict-based learning model, the STEM approach, and AR technology is essential to create more interactive, effective, and student-centered learning experiences.

D. Critical Thinking Skills

Critical thinking is defined as the ability to think reasonably, reflectively, and purposefully in making sound decisions [49]. Ennis [50] highlights that critical thinking involves the ability to develop a thesis, locate sufficient information, use credible sources, and analyze arguments. The framework of critical-thinking skills is further described by Facione [51], who identifies six core skills: interpretation, analysis, evaluation, inference, explanation, and self-regulation. In addition, several important dispositions are required to support critical thinking, including curiosity, intellectual openness, clarity, persistence, and logical reasoning. Another perspective asserts that critical thinking is a key competency involving the ability to analyze, evaluate, and reflect on scientific phenomena [52]. In the context of physics education, this competency is manifested through activities such as formulating questions, proposing hypotheses, drawing conclusions, considering alternative possibilities, and systematically designing experiments. These abilities are essential because students are expected to identify problems, interpret data, validate experimental evidence, and draw logical conclusions [53]. Overall, based on these definitions, critical thinking in physics learning is directed toward uncovering facts through systematic and in-depth reasoning.

Research conducted in Indonesia indicates that students' critical-thinking skills in physics remain low, especially in their abilities to analyze and draw conclusions [18]. Moreover, recurring misconceptions that are not addressed effectively continue to hinder the development of students' analytical abilities [17]. Although various instructional strategies and learning media have been developed to enhance critical thinking [54], their effectiveness remains inconsistent because most approaches focus primarily on content delivery and do not sufficiently address deeper cognitive processes.

Based on this review, efforts to enhance critical thinking skills in physics learning remain suboptimal. Existing approaches have not yet positioned critical thinking skills as a core objective integrated with modern technologies and pedagogical principles. Referring to Ennis's framework, improvement is needed in students' abilities to formulate hypotheses, analyze information, draw conclusions, and design experiments [50]. These gaps highlight the need for a more integrative, contextual, and adaptive learning approach that aligns with students' needs [55].

The integration of innovative media such as AR, STEM approaches, and cognitive-conflict-based learning models has the potential to provide learning experiences that foster students' reflective and analytical thinking. The combination of technology, pedagogy, and cognitive strategies offers aligned features and sequences that can strengthen critical thinking processes, which have not yet been fully maximized. Therefore, research is needed to design physics instruction that explicitly develops critical thinking skills through the integration of modern media and relevant pedagogical approaches, particularly by adopting AR technology, STEM approaches, and cognitive conflict-based learning models.

III. Materials and Methods

The Educational Design Research (EDR) approach was applied in the development process of the physics website. This approach consists of three main stages: (1) analysis and exploration, (2) design and construction, and (3) evaluation and reflection [56]. The first stage, analysis and exploration, aimed to identify and investigate the needs for developing the physics website based on learning characteristics and students' perceptions. This analysis and exploration were conducted through a needs survey, considering important aspects such as socio-emotional aspects, efficiency, actual behavior, and preferences. The second stage, design and construction, utilized the findings from the first stage to develop a prototype of the website based on the physics learning framework. At this stage, the alignment principle between students' needs and learning characteristics was strongly emphasized to create a systematic and conducive learning framework to support students' critical thinking skills. The third stage, evaluation and reflection, was limited to the expert review process. This reflects the overall scope of the present study, which focused solely on the design and validation phases and did not extend to classroom implementation or empirical testing. This limitation opens opportunities for future researchers to conduct longitudinal evaluations and apply experimental research designs to examine the website's effectiveness in real learning environments. The expert review involved specialists in education, physics, and technology to validate the design of the developed physics website. This validation aimed to ensure the clarity, relevance, and feasibility of the design before its further implementation. All stages of the research design are presented in Fig. 1.

Fig. 1. Research stages.

A. Participants

The research data were collected from 404 students and 6 experts. The students participating in this study were drawn from upper secondary schools in West Sumatra, Indonesia. They were selected using a random sampling technique to ensure representation across diverse social, economic, and

geographical contexts. Of the total students, 157 were male and 247 were female, with ages ranging from 16 to 18 years old. Meanwhile, the experts involved in this study came from the fields of education, physics, and technology. They were selected based on strict competency criteria, including more than 10 years of professional experience in their respective fields, scientific publications, and active involvement in the development of educational technology. These experts' role was to validate the physics website design. All research procedures obtained ethical approval from the Research Ethics Committee of Universitas Negeri Padang. Participation was voluntary with informed consent from all respondents, in accordance with international research ethics principles.

B. Instrument and Procedures

The data were obtained through a needs analysis instrument administered to students and a validation instrument completed by experts. All items in the questionnaire employed a five-point Likert scale, with response options ranging from 1 (strongly disagree) to 5 (strongly agree). The research instruments were designed contextually and in line with the development objectives, and they had undergone a validation process to ensure content validity. The main indicators of the student needs analysis instrument are presented in Table 1, while the expert validation indicators are shown in Table 2.

Table 1. Student instrument indicators

Code	Indicator Description	Category
A1	Enjoy learning through digital platforms	Actual behavior
A2	Require interactive diagnostic assessments.	
A3	Interested in challenging physics phenomena	
A4	Need virtual experiments in learning.	
A5	Assessment feedback improves understanding.	
A6	Digital assessments reduce anxiety.	
A7	Three-dimensional visualization of physics phenomena	
A8	Like critical-thinking physics problems	
A9	Learn with images, videos, and animations.	
A10	Understand the meaning and application of formulas.	
A11	Technology supports conceptual understanding in physics.	
A12	Design science-based solutions	
S1	Enjoyable and emotionally supportive	Socio-emotional
S2	Enhances self-confidence	
S3	Positively connected with the subject matter.	
S4	Motivates systematic learning of physics	
S5	Guides disciplined task engagement.	
S6	Digital learning is not monotonous.	
S7	Allows comfortable self-paced learning	
P1	Smartphones support the understanding of learning materials	Preferences
P2	Smartphones enhance physics knowledge.	
P3	Smartphones facilitate the expression of ideas.	
P4	Smartphones enable checking of physics understanding.	
P5	Smartphones increase learning motivation.	
P6	Smartphones assist in problem-solving	
P7	Smartphones are predominantly used for entertainment.	
E1	Better time management	Efficiency
E2	Efficient and well-directed learning	
E3	AR accelerates conceptual understanding.	
E4	Practical and cost-effective solution	
E5	Enhances independent learning effectiveness	

Table 2. Expert instrument indicators

Code	Indicator Description	Category
L1	The learning materials are systematically organized within a cognitive conflict-based learning model framework to promote knowledge construction and critical thinking.	Learning Content
L2	The 3D/AR phenomena are relevant to daily life and technological contexts.	
L3	Physics concepts, symbols, and terminology are applied accurately and consistently.	
L4	The language is clear, communicative, and appropriate to students' cognitive levels.	
I1	The STEM components are presented comprehensively.	Instructional Design
I2	The learning indicators are aligned with critical thinking skills.	
I3	The learning stages are presented systematically in accordance with the cognitive conflict learning model.	
LN1	Basic navigation functions (menu, close, back) operate properly.	Layout and navigation
LN2	Fonts are clearly readable, with a proportional and visually appealing layout.	
LN3	3D/AR objects can be observed effectively without slowing down the slides.	
LN4	User instructions are clear and accurate.	
SU1	The software effectively supports the visualization of 3D/AR objects and physics website simulations.	Software utilization
SU2	The physics website is both interactive and original in its support of the learning process.	
SU3	The software effectively supports the visualization of 3D/AR objects and physics website simulations.	

C. Data Analysis

Data obtained from the student needs analysis instrument were analyzed using descriptive and inferential statistics to describe participants' perceptions of product development requirements. The analysis included calculating Means (M), percentages (%), and Standard Deviations (SD) to identify the perceived level of needs. The analysis of perceptions was conducted using t-tests and ANOVA to examine differences

based on gender and grade level. These tests were selected based on the results of normality and homogeneity tests. The interpretation of differences in perceptions between gender and grade was based on the p-value. If $p < 0.05$, the result indicates a statistically significant difference. In addition, data obtained from experts were used to evaluate product validity through content validity testing. Product validity was analyzed using Aiken's V Index (V). This quantitative method assesses the extent to which experts rate items as relevant. The acceptance criterion was set at an Aiken's V value of ≥0.80, which indicated that the item was valid [57]. Conversely, if the V value was <0.80, the item was considered invalid and required revision.

IV. Result

A. Characteristics of Learning that Integrate a Physics Website with AR, a Cognitive Conflict-Based Learning Model, and a STEM Approach

The analysis and exploration of learning needs were conducted to identify the characteristics of learning that integrate a physics website incorporating AR, a cognitive conflict-based learning model, and a STEM approach in physics instruction. Learning that incorporates digital technology plays a crucial role in creating balanced learning opportunities for students. In physics learning, the need for contextual content delivery and the representation of real-world phenomena cannot be overlooked. Based on the needs analysis, visualization in physics learning emerged as one of the most urgent priorities, as many concepts are abstract, difficult to observe directly, or limited in representation due to objects being too large, too small, or too hazardous to observe. Therefore, using technology-based media to provide a more realistic visualization of phenomena becomes a relevant alternative.

One technology with great potential to address this challenge is AR. The primary characteristic of AR lies in its ability to visualize objects in interactive, three-dimensional forms that are contextualized. With this feature, AR allows students to explore physics objects in detail without losing informational completeness. In addition to offering visualization that closely approximates real conditions, AR also supports the simulation of phenomena, enhancing students' understanding by transforming abstract concepts into more concrete forms.

The STEM approach was employed to support learning that emphasizes visualization and highlights the integration of knowledge and skills. This approach provides a holistic framework that integrates four key elements:

1) Science: Understanding scientific phenomena through observation and analysis.
2) Technology: Utilizing technology (in this case, AR) to support learning.
3) Engineering: Developing design, creation, and problem-solving skills through experimental activities.
4) Mathematics: Applying mathematical concepts to model and verify physical principles.

Integrating these four elements provides an authentic, contextual, and applicable learning experience, equipping students with critical thinking skills required in the 21st century. A learning model that addresses misconceptions while promoting critical thinking skills is required to systematically integrate AR and STEM-based learning. The cognitive conflict-based learning model was selected due to its characteristics, which emphasize the reconstruction of students' understanding through the following stages:

1) Activation of preconceptions: Exploring students' prior knowledge to identify misconceptions.
2) Presentation of cognitive conflict: Presenting phenomena or problems that contradict students' preconceptions to trigger cognitive disequilibrium.
3) Discovery of concepts and equations: Guiding students to discover the correct concepts through experiments, discussions, and AR media.
4) Reflection: Providing opportunities for students to reflect on the newly acquired understanding, compare it with their initial preconceptions, and internalize the correct concepts.

All the essential components of physics learning characteristics are integrated into a single website. The choice of a website is based on its ability to provide broad and flexible access, enabling the combination and organization of various learning characteristics into a coherent and unified system. The integration of AR technology, the STEM approach, and the cognitive conflict-based learning model within the website is expected to create a visually engaging learning experience, strengthen conceptual understanding, and support students' critical thinking skills.

B. Students' Perceptions on AR-Assisted Physics Learning in Terms of Socio-Emotional, Efficiency, Actual Behavior, and Preferences

Students were also analyzed and explored to identify their perceptions of AR-assisted physics learning in terms of socio-emotional aspects, efficiency, actual behavior, and preferences. The instrument used to measure students' perceptions had been tested for validity and reliability to ensure its quality. The validity test was conducted by involving 60 students outside the research sample. The instrument was considered valid and reliable if the significance value was $p < 0.05$ and Cronbach's Alpha (α) > 0.90 [58, 59]. The analysis results showed that all items of the instrument met these standard values, as presented in Table 3. These findings indicate that the instrument used in this study was both valid and reliable.

Table 3 presents the results of the validity and reliability tests for the instrument. The findings indicate that all items were confirmed to be both valid and reliable. The instrument was then used to measure students' perceptions of AR-assisted physics learning, examining socio-emotional aspects, efficiency, actual behavior, and preferences. The data obtained from students' perceptions are displayed in Table 4.

Table 4 shows that students' perceptions of technology-based physics learning were generally positive across all measured aspects on a 1–5 scale. The socio-emotional aspect recorded a high mean score ($M = 3.89$, $SD = 0.58$), indicating that students felt emotionally prepared and comfortable when engaging with digital media. The efficiency aspect also received a favorable evaluation ($M = 3.79$, $SD = 0.60$), indicating that technology was perceived as supporting autonomous learning and facilitating

effective conceptual understanding. Additionally, the preference aspect (M = 3.92, SD = 0.53) revealed a strong tendency among students to select digital tools as their preferred learning support. The actual behavior aspect displayed similarly positive responses (M = 3.87, SD = 0.50), reflecting students' perception of the usefulness of images, videos, animations, and AR in enriching their learning experience. The predominance of "agree" and "strongly agree" responses across these aspects indicates consistent approval of the technology used. Overall, the data demonstrate that students exhibited positive socio-emotional readiness, learning efficiency, media preference, and actual behavioral engagement when interacting with technology-based physics learning materials.

Table 3. Validity and reliability of student instrument indicators

Code	CITC	α	p
A1	0.775	0.951	0.000
A2	0.533	0.953	0.000
A3	0.562	0.953	0.000
A4	0.631	0.952	0.000
A5	0.518	0.953	0.000
A6	0.299	0.955	0.000
A7	0.646	0.952	0.000
A8	0.583	0.952	0.000
A9	0.535	0.953	0.000
A10	0.456	0.953	0.000
A11	0.586	0.952	0.000
A12	0.580	0.952	0.000
P1	0.627	0.952	0.000
P2	0.763	0.951	0.000
P3	0.767	0.951	0.000
P4	0.729	0.951	0.000
P5	0.728	0.951	0.000
P6	0.741	0.951	0.000
P7	0.204	0.957	0.000
S1	0.678	0.952	0.000
S2	0.633	0.952	0.000
S3	0.700	0.951	0.000
S4	0.707	0.951	0.000
S5	0.731	0.951	0.000
S6	0.696	0.951	0.000
S7	0.679	0.952	0.000
E1	0.693	0.951	0.000
S2	0.694	0.951	0.000
E3	0.661	0.952	0.000
E4	0.696	0.951	0.000
E5	0.699	0.951	0.000

Note. CITC: Corrected Item-Total Correlation

Table 4. Student perception results

Aspects	Mean			SD	SA (%)	A (%)	N (%)	D (%)	SD (%)
	Min	Max	Total						
Socio-emotional	3.78	4.02	3.89	0.58	22.3	47.2	27.6	2.4	0.4
Efficiency	3.72	3.89	3.79	0.60	18.4	46.0	31.5	3.9	0.1
Preferences	3.25	4.11	3.92	0.53	25.8	45.3	25.1	3.0	0.8
Actual behavior	3.58	4.15	3.87	0.50	23.0	43.8	30.6	2.4	0.3

Note. *SA* = Strongly agree; *A* = Agree; *N* = Neutral; *D* = Disagree; *SD* = Strongly disagree

C. Students' Perceptions by Gender

Students' perceptions were categorized by gender, specifically male and female. To compare the perceptions between the two groups, an independent samples t-test was employed, as this method is appropriate for examining differences between two independent groups. The test was conducted to minimize potential bias and to determine whether there were significant differences in students' perceptions according to gender. These results are presented in Table 5.

Table 5. Results of student perceptions based on gender

Aspects	Male (n = 157)		Female (n = 247)		Independent Sample t-test			Effect Size (Cohen's d)
	M	SD	M	SD	df	t	p	
Socio-emotional	3.93	0.62	3.86	0.55	402	1.28	0.20	0.13
Efficiency	3.84	0.65	3.75	0.56	402	1.46	0.14	0.14
Actual behavior	3.93	0.57	3.92	0.50	402	0.03	0.97	0.01
Preferences	3.91	0.54	3.84	0.47	402	1.41	0.15	0.14
Total	3.90	0.54	3.84	0.44	402	1.23	0.21	0.12

Note. M = Mean; SD = Standard deviation; Effect size ≤ 0.2 (Very small effect))

Table 5 shows that the mean scores total for male (M = 3.90, SD = 0.54) and female students (M = 3.84, SD = 0.44) were relatively similar. Furthermore, the independent samples t-test indicated no significant differences in students' perceptions of technology-based physics learning between male and female groups. This is reflected by the nonsignificant p-values ($p > 0.05$) across the socio-emotional, efficiency, actual behavior, preference, and total score

aspects. The effect sizes were very small ($d < 0.20$), further confirming the absence of meaningful gender differences. These findings suggest that students' perceptions of technology use in physics learning were uniform across genders on all measured aspects.

D. Comparison of Students' Perceptions across Grade Levels

Students' perceptions were further categorized according to grade level in upper secondary school, specifically grades 1, 2, and 3. The data from these three groups were analyzed using ANOVA to determine whether significant differences in perceptions existed across grade levels. This analysis aimed to identify relevant needs based on the measured aspects. The decision criterion was $p < 0.05$, indicating a significant difference among students from different grade levels. The results revealed that the p-values exceeded 0.05 for all aspects, suggesting no significant differences in perceptions across grade levels. These findings are presented in Table 6.

Table 6. Student perceptions results based on grade

Aspects	Grade 1 (N = 153)		Grade 2 (N = 127)		Grade 3 (N = 124)		ANOVA Results						
	M	*SD*	*M*	*SD*	*M*	*SD*	df1	df2	SS Between	SS Total	*F*	*p*	Effect size η^2
Socio-emotional	3.95	0.54	3.85	0.60	3.84	0.59	2	401	1.062	136.568	1.57	0.20	0.0078
Efficiency	3.82	0.57	3.77	0.61	3.75	0.61	2	401	0.36	145.213	0.49	0.60	0.0025
Actual behavior	3.92	0.50	3.97	0.52	3.86	0.56	2	401	0.682	112.917	1.21	0.29	0.006
Preferences.	3.89	0.50	3.85	0.48	3.86	0.52	2	401	0.11	102.642	0.21	0.80	0.0011
Total	3.89	0.47	3.86	0.48	3.82	0.49	2	401	0.29	95.247	0.61	0.54	0.003

Note. M = Mean; SD = Standar deviation; df_1 = Degrees of freedom between groups; df_2 = Degrees of freedom within groups; SS = Sum of squares; η^2 = Eta Squared; Effect size ≤ 0.2 (Very small effect))

Table 6 shows that the mean scores total for Grade 1 (M = 3.89, SD = 0.47), Grade 2 (M = 3.86, SD = 0.48), and Grade 3 students (M = 3.82, SD = 0.49) were relatively similar. Furthermore, the ANOVA results indicated no significant differences in students' perceptions of technology-based physics learning across the three grade levels. This is demonstrated by nonsignificant p-values ($p > 0.05$) for all aspects, including socio-emotional, efficiency, actual behavior, preference, and the total score. The effect sizes ($\eta^2 < 0.20$) also reflected a very small effect. These findings suggest that students' perceptions of technology use in physics learning were consistent across grade levels for all measured aspects. This uniformity of perception suggests that students across all grade levels share similar needs related to the four measured aspects, indicating that these consistently observed needs can serve as a basis for characterizing the design requirements of web-based learning media.

E. Result of The Framework, The Resulting Website Product, and The Validity of The Integrative Physics Website in Facilitating Students' Critical Thinking Skills

The design and development of the physics website were carried out within the framework of physics learning, taking into account the characteristics of instruction and students' perceptions of learning physics, particularly the need for media that are interactive, contextual, and easily integrated into classroom settings. The design integrates four core components: interactive website features, AR technology, the STEM approach, and a cognitive conflict-based learning model. These elements were combined into a single web-based platform that systematically and structurally presents physics content while supporting meaningful learning experiences to support students' critical thinking skills.

The primary focus of this design is the integration of STEM components: Science (understanding phenomena), Technology (utilization of AR), Engineering (designing virtual experiments), and Mathematics (modeling equations) within one holistic learning experience. The integrated physics learning framework is illustrated in Fig. 2, which was subsequently realized and developed into a fully functional learning website, as shown in Fig. 3.

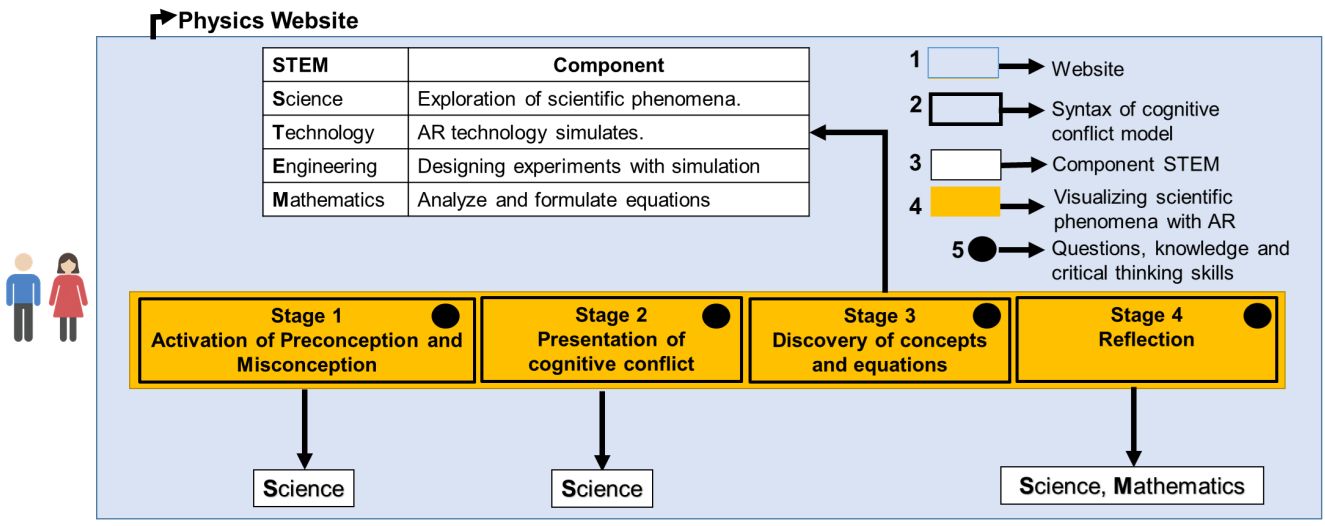

Fig. 2. Physics learning framework.

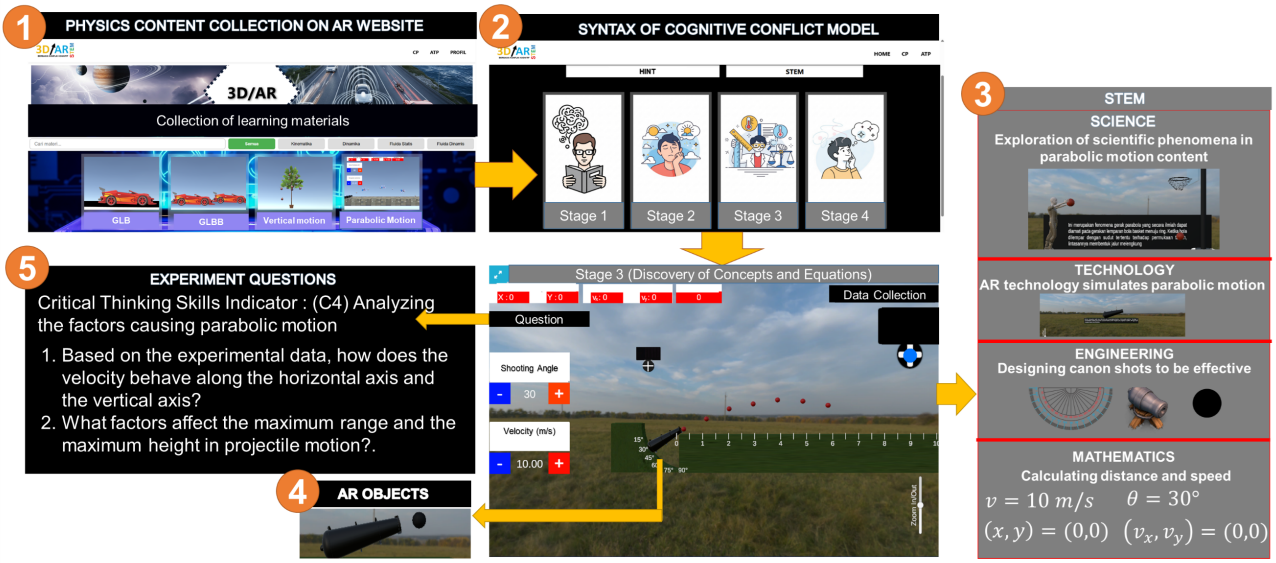

Fig. 3. Design of a website based on the physics learning framework.

Fig. 2 illustrates the integration pathway among AR, STEM, and the cognitive conflict–based learning model. Each stage within the cognitive conflict-based learning model represents systematically integrated STEM components, designed based on indicators of critical thinking skills, so that every question and learning process is oriented toward developing students' critical thinking skills. The implementation of this integration framework is visualized in Fig. 3, which presents the design of a web-based learning platform consisting of five main components: (1) the main menu displaying physics learning materials, (2) the stages of the cognitive conflict–based learning model, (3) STEM-based learning content, (4) AR objects, and (5) critical thinking skills oriented question indicators and learning flow.

The first component, the main menu interface, contains collections of physics learning materials and serves as an entry point to all learning content. One of the accessible materials from this menu is projectile motion. The second component presents the stages of the cognitive conflict-based learning model, directing each content access toward activities that align with the respective stage. One example, such as the concept and equation discovery stage, integrates STEM components, AR objects, and critical thinking indicators designed to enhance students' analytical and problem-solving abilities.

The third component consists of a STEM approach, systematically integrated into the process of concept and equation discovery. The contextual presentation of projectile motion phenomena, visualized through AR, represents the Science component. The Technology component is implemented through AR-based simulations, enabling students to interactively observe and explore the characteristics of projectile motion. The Engineering element is realized through virtual experiment design features, allowing students to manipulate variables such as launch angle and initial velocity to determine the projectile's maximum range. The mathematics component is represented through data calculation and analysis activities that guide students in formulating relevant mathematical concepts and equations.

The fourth component comprises AR objects, which support visual and interactive presentations through 3D models and dynamic simulations, allowing students to directly engage with physical phenomena in a contextualized environment. Meanwhile, the fifth component presents critical thinking question indicators that guide students in collecting data, analyzing experimental results, testing hypotheses, and discovering concepts and equations through exploratory activities in the virtual laboratory.

Overall, all elements in the web-based platform are designed in an integrated manner to enhance students' critical thinking skills through virtual experiments, conceptual analysis, and problem-solving activities. The integration of AR, STEM, and the cognitive conflict-based learning model enables physics learning to become more interactive, contextual, and focused on developing critical thinking skills.

The developed physics website is an interactive digital platform designed to support visual and exploratory learning in physics. The development process integrated several supporting software tools. Blender was used to create 3D objects that realistically represent physical phenomena, while Unity was employed to animate these objects, creating interactive simulations that enable users to engage dynamically with physics concepts. All components were integrated into a single cohesive website using a hosting system that allows easy access across various devices. The final product is an interactive digital physics learning platform that can be accessed online at https://cognitiveconflict.id/.

The website features multiple interactive components, including 3D visualizations and AR displays to enhance students' understanding of abstract physics concepts. Users can navigate materials through interactive buttons organized by topic. The website also provides practice exercises, including multiple-choice and short-answer questions, with automated feedback for each response. Additionally, it offers a virtual experiment feature that allows users to perform simulations and observe results in real-time, supported by a data recording table to facilitate analysis of experiment results.

The design and construction phase was followed by evaluation and reflection. This process involved experts who assessed the quality of the website design. The website and its

embedded learning content underwent expert validation to ensure alignment with physics education standards and the feasibility of technology integration. The results of the expert validation are presented in Table 7.

Table 7. Validity test results

Indicator	Average
Learning Content	0.98
Instructional Design	0.95
Layout and navigation	0.93
Software utilization	0.94

Table 7 presents the mean validity scores provided by experts for the physics learning website. The analysis indicates that the learning content achieved an average score of 0.98, instructional design achieved a score of 0.95, layout and navigation achieved a score of 0.93, and software utilization achieved a score of 0.94. These values exceeded the minimum validity standard ($V > 0.80$), suggesting that the website can be categorized as highly valid and feasible for physics learning.

V. Discussion

A. Students' Perceptions on Physics Learning in Terms of Socio-Emotional, Efficiency, Actual Behavior, and Preferences

The results of the preliminary survey analysis revealed a consistency between students' perceptions and the expected characteristics of technology-based learning. These findings indicate that students' readiness and perceptions toward digital learning encompass four main aspects: socio-emotional aspects, efficiency, actual behavior, and learning preferences. From the socio-emotional perceptions, students demonstrated comfort and positive engagement with technology-based learning. This result is consistent with the findings of Tan and Chen [60], who stated that the use of technology can influence the socio-emotional aspects of students in the learning process, particularly in building self-confidence and positive attitudes toward digital learning.

In terms of efficiency, students perceived digital learning, especially with the support of AR, as more practical and time-efficient. Amlasri [61] also emphasised that technology plays a crucial role in accelerating the understanding of abstract physics concepts while promoting independent learning. This finding aligns with previous studies that emphasise the importance of integrating technology in creating systematic learning processes that foster students' thinking skills. Interactive learning activities, which support critical thinking skills, are viewed as a relevant solution [62, 63].

Regarding actual behavior, students demonstrated consistent habits in using digital devices, particularly smartphones, to support their learning activities. They also tended to prefer platforms featuring interactive tools such as AR, virtual experiments, and 3D visualisations. This pattern suggests that students have a learning tendency driven by exploration and verification of concepts. Therefore, the integration of the cognitive conflict-based learning model and the STEM approach serves as a mutually reinforcing combination, as both promote analytical and reflective thinking processes [64].

In terms of preferences, students showed a high interest in visualisation and simulation-based learning media, as these provide engaging, interactive, and relevant learning experiences that are suited to current needs. Digital learning was also perceived as capable of enhancing motivation, discipline, and self-confidence [65]. These findings reinforce the view that interactive design and the integration of innovative technologies such as AR play a crucial role in improving student engagement and learning satisfaction [66, 67]. These results imply that the preliminary survey provides a crucial foundation for developing a physics website that integrates the STEM approach and the cognitive conflict-based learning model to support critical thinking skills.

B. Gender and Grade Analysis

The analysis reveals that there are no significant differences in students' perceptions of technology-based physics learning based on gender or grade level, which has important implications for the development of universally designed digital learning environments. This result indicates that both male and female students, across different academic levels, share relatively similar views and needs regarding the use of technology in physics learning, covering socio-emotional, efficiency, actual behavior, and preference aspects.

From the socio-emotional perceptions, students demonstrated comfort and positive engagement with technology-based learning. This finding is consistent with O'Connor and Liu [68], who found that technology readiness is not influenced by gender, thereby minimising bias in technology adoption. Regarding efficiency, all groups perceived technology as helpful in enhancing effectiveness and accelerating conceptual understanding in physics, supporting Timotheou *et al.* [69], who emphasized the importance of digital efficiency for modern learners.

In terms of actual behaviour, students across all grade levels demonstrated comparable participation in technology-based learning activities. This finding aligns with Wang *et al.* [70], who noted that digital learning experiences can adapt across varying levels of ability. Meanwhile, regarding preferences, students in all groups showed a similar interest in visualization and simulation-based media, underscoring the importance of interactive design in fostering learning motivation. Overall, the findings reveal no significant differences in students' perceptions based on gender or grade level, indicating shared needs and expectations in physics learning consistent with previous studies.

C. Design of a Website for Physics

The design of the physics website was developed by carefully considering students' perceptions and the characteristics of learning needs. This strengthens the rationale for developing the physics website design that integrates AR, the cognitive conflict-based learning model, and the STEM approach. Previous studies have shown that STEM effectively presents content that guides students toward deeper thinking [71]. Integrating AR and STEM reinforces conceptual understanding and students' skills [72]. Applying a cognitive conflict-based learning model integrated with STEM appeared to meet these needs. STEM-based learning has also promoted socio-emotional

engagement and enhanced learning motivation [73, 74].

The findings of this study indicate that the physics website developed is systematically structured according to the stages of the cognitive conflict–based learning model integrated with AR and the STEM approach. These three components form a unified system through interrelated features that support students' critical thinking skills, as illustrated in Fig. 3. Unlike previous AR developments, which were commonly presented in APK (Android Application Package) format [75] and focused on static visualizations [76–78], this study introduces interactive and dynamic AR objects. The integration of APK and website access enables students to manipulate AR objects and conduct virtual experimental simulations.

The features embedded in the website are explicitly designed to support cognitive processes associated with critical thinking, following Ennis's framework. These include tools for formulating hypotheses, analyzing evidence-based information through AR simulations, designing experiments via a virtual laboratory aligned with the STEM approach, and drawing conclusions. The features are presented interactively, providing students with immediate feedback for each question they answer, including scores and explanations aligned with correct physics concepts. All components are integrated into the stages of the cognitive conflict–based learning model, ensuring that each stage fulfills cognitive functions consistent with indicators of critical thinking. These findings are consistent with previous studies demonstrating the effectiveness of the cognitive conflict model in addressing misconceptions and strengthening analytical and critical thinking skills [24, 45, 48]. Overall, the design of this physics website has been developed to support the enhancement of students' critical thinking skills in physics learning.

D. Validation of the Physics Website

The expert validation score, indicated by an Aiken's V value greater than 0.8, demonstrates a very high level of content validity. This result confirms that the developed website is strongly aligned with expert expectations in terms of pedagogical quality. Furthermore, all evaluated aspects including learning content, instructional design, layout and navigation, and software utilization met the criteria of valid and well-structured design components.

The user-friendly interface and intuitive navigation were essential factors supporting learning effectiveness, consistent with literature emphasizing the impact of visual design and interactivity on student engagement [79–81]. The content and instructional design structure were central to the development of technology-based learning, which must be systematically organized and relevant [82, 83]. The website was developed with content and instructional structures aligned with the stages of the cognitive conflict-based learning model and the STEM approach.

The findings of this study indicate that the instructional components and interactive elements of the website were judged to be highly appropriate and theoretically valid, demonstrating strong potential to support the development of students' critical thinking skills. The developed website offers practical implications for teachers and students, as its features allow for easy integration into both classroom-based and hybrid learning environments. The platform is open-access and can be used through computers or smartphones without requiring any additional software installation, enabling teachers to integrate it directly into their lesson plans. The step-by-step structure based on the cognitive conflict model helps teachers manage the learning process systematically, while also guiding students to follow the learning sequence more clearly.

Furthermore, the website provides immediate feedback on each quiz, playing a crucial role in supporting self-directed learning. The virtual laboratory feature enables flexible experimentation and helps overcome limitations in physical laboratory facilities. This exploratory environment not only enriches students' conceptual understanding but also fosters curiosity and supports the development of critical thinking skills through independent inquiry.

Overall, the integration of these features demonstrates that the developed physics website holds considerable practical potential for enhancing physics learning. Nevertheless, since this study was limited to the design and validation stages, further research is needed to investigate its impact on learning processes and outcomes through longitudinal experimental studies. Additional investigation of other variables that may influence learning outcomes is also recommended to obtain a more comprehensive understanding of the website's effectiveness in physics education.

VI. Conclusions and Implications

This study has developed a physics website based on cognitive conflict, AR, and STEM within the physics learning framework to support students' critical thinking skills. The design was constructed by considering learning characteristics and students' perceptions, realized as a physics website product, and validated by experts. The design's key features include the integration of AR, the cognitive conflict-based learning model, and the STEM approach, which synergistically supports the development of critical thinking skills. Students' perceptions were analyzed through four main aspects: socio-emotional, efficiency, actual behavior, and preference. The analysis indicates strong student support for learning that utilizes AR phenomena, the STEM approach, and the stages of a cognitive conflict-based learning model to strengthen critical thinking. The findings also suggest no significant differences in perceptions based on gender or grade level.

These student characteristics and needs were the foundation for developing the physics website. Expert evaluation of the learning content, instructional design, layout, navigation, and software utilization demonstrated that all aspects fell into the valid category. Therefore, the resulting physics website design meets the feasibility standards for use in physics learning. Based on these findings, it is recommended that physics websites utilize AR, cognitive conflict-based learning models, and STEM elements to support students' critical thinking skills in physics teaching.

Nevertheless, this study has several limitations. The scope of the research is restricted to the design and validation stages, without conducting empirical classroom implementation or longitudinal testing to evaluate the website's effectiveness in actual learning contexts. A stepwise evaluation with iterative revisions is still required to produce a fully mature and

high-quality product. Future studies are therefore planned to empirically examine the website's impact on students' learning outcomes, including long-term effectiveness, as well as students' motivation and technology acceptance. Furthermore, future research is encouraged to explore other learning approaches and integrate additional innovative technologies to further enhance the website's educational impact.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

F.M. conceptualized the study, designed the research, collected data, validated the findings, and provided funding. E.E. contributed to the validation of the results, evaluation, and data collection. H.H. was involved in validating the results, evaluating the data, and collecting data. Y.H. contributes to validating AR media in the subject of digital learning media. M.D. contributed to website design, AR development, framework construction, and manuscript writing. Z.F. designed the website cover and managed the research administration. All authors had approved the final version.

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REFERENCES

[1] A. Alam and A. Mohanty, "Educational technology: Exploring the convergence of technology and pedagogy through mobility, interactivity, AI, and learning tools," *Cogent Engineering*, vol. 10, no. 2, 2283282, 2023. doi: 10.1080/23311916.2023.2283282

[2] L. I. González-Pérez and M. S. Ramírez-Montoya, "Components of education 4.0 in 21st century skills frameworks: Systematic review," *Sustainability*, vol. 14, no. 3, 1493, 2022 doi: 10.3390/su14031493

[3] H. Herlinawati, M. Marwa, N. Ismail, L. O. Liza, and D. D. B. Situmorang, "The integration of 21st century skills in the curriculum of education," *Heliyon*, vol. 10, no. 15, 2024. doi: 10.1016/j.heliyon.2024.e35148

[4] G. M. Francom, S. J. Lee, and H. Pinkney, "Technologies, challenges and needs of K-12 teachers in the transition to distance learning during the COVID-19 pandemic," *TechTrends*, vol. 65, no. 4, pp. 589–601, 2021. doi: 10.1007/s11528-021-00625-5

[5] S. F. Griffith, M. B. Hagan, P. Heymann, B. H. Heflin, and D. M. Bagner, "Apps as learning tools: A systematic review," *Pediatrics*, vol. 145, no. 1, e20191579, 2020. doi: 10.1542/peds.2019-1579

[6] F. Arena, M. Collotta, G. Pau, and F. Termine, "An overview of augmented reality," *Computers*, vol. 11, no. 2, 28, 2022. doi: 10.1007/978-3-319-54502-8_4

[7] C. Avila-Garzon, J. Bacca-Acosta, J. Duarte, and J. Betancourt, "Augmented reality in education: An overview of twenty-five years of research,"*Contemporary Educational Technology*, vol. 13, no. 3, 2021. doi: 10.3390/mti5070037

[8] S. Salimi, Z. Asgari, A. Mohammadnejad, A. Teimazi, and M. Bakhtiari, "Efficacy of virtual reality and augmented reality in anatomy education: A systematic review and meta-analysis," *Anatomical Sciences Education*, vol. 17, no. 9, pp. 1668–1685, 2024. doi: 10.1002/ase.2501

[9] C. Weng, S. Otanga, S. M. Christianto, and R. J. C. Chu, "Enhancing students' biology learning by using augmented reality as a learning supplement," *Journal of Educational Computing Research*, vol. 58, no. 4, pp. 747–770, 2020. doi: 10.1177/0735633119884213

[10] F. Mufit and M. Dhanil, "Effectiveness of augmented reality with cognitive conflict model to improve scientific literacy of static fluid material," *International Journal of Information and Education Technology*, vol. 14, no. 9, 2024. doi: 10.18178/ijiet.2024.14.9.2149

[11] C. M. Rebello, G. F. Deiró, H. K. Knuutila, L. C. de Souza Moreira, and I. B. R. Nogueira, "Augmented reality for chemical engineering education," *Education for Chemical Engineers*, vol. 47, pp. 30–44, 2024. doi: 10.1016/j.ece.2024.04.001

[12] A. Fombona-Pascual, J. Fombona, and R. Vicente, "Augmented reality, a review of a way to represent and manipulate 3D chemical structures," *Journal of Chemical Information and Modeling*, vol. 62, no. 8, pp. 1863–1872, 2022, doi: 10.1021/acs.jcim.1c01255

[13] I. Radu, J. Yuan, X. Huang, and B. Schneider, "Charting opportunities and guidelines for augmented reality in makerspaces through prototyping and co-design research," *Computers and Education: X Reality*, Elsevier, 2023. doi: 10.1016/j.cexr.2023.100008

[14] A. A. Ziden, A. A. A. Ziden, and A. E. Ifedayo, "Effectiveness of Augmented Reality (AR) on students' achievement and motivation in learning science," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 18, no. 4, em2097, 2022. doi: 10.29333/ejmste/11923

[15] F. Arici, "Investigating the effectiveness of augmented reality technology in science education in terms of environmental literacy, self-regulation, and motivation to learn science," *International Journal of Human–Computer Interaction*, vol. 40, no. 24, pp. 8476–8496, 2024, doi: 10.1080/10447318.2024.2310921

[16] M. Perifanou, A. A. Economides, and S. A. Nikou, "Teachers' views on integrating augmented reality in education: needs, opportunities, challenges and recommendations," *Future Internet*, vol. 15, no. 1, 20, Dec. 2022. doi: 10.3390/fi15010020

[17] R. Puspitasari, F. Mufit, and Asrizal, "Conditions of learning physics and students' understanding of the concept of motion during the covid-19 pandemic," *Journal of Physics: Conference Series*, vol. 1876, no. 1, 2021. doi: 10.1088/1742-6596/1876/1/012045

[18] P. D. A. Putra, N. F. Sulaeman, Supeno, and S. Wahyuni, "Exploring students' critical thinking skills using the engineering design process in a physics classroom," *The Asia-Pacific Education Researcher*, vol. 32, no. 1, pp. 141–149, 2023. doi: 10.1007/s40299-021-00640-3

[19] T. Musengimana, L. L. Yadav, J. Uwamahoro, and G. Nizeyimana, "Assessing physics students' problem-solving skills: A baseline investigation," *Discover Education*, vol. 4, no. 1, 196, 2025. doi: 10.1007/s44217-025-00640-1

[20] E. Sjølie, T. C. Espenes, and R. Buø, "Social interaction and agency in self-organizing student teams during their transition from face-to-face to online learning," *Computers and Education*, vol. 189, 104580, 2022. doi: 10.1016/j.compedu.2022.104580

[21] Y. Lai, N. Saab, and W. Admiraal, "University students' use of mobile technology in self-directed language learning: Using the integrative model of behavior prediction," *Computers and Education*, vol. 179, 104413, 2022. doi: 10.1016/j.compedu.2021.104413

[22] S. Fajrina, L. Lufri, and Y. Ahda, "Science, Technology, Engineering, and Mathematics (STEM) as a learning approach to improve 21st century skills: A review," *International Journal of Online and Biomedical Engineering*, vol. 16, no. 7, 2020. doi: 10.3991/ijoe.v16i07.14101

[23] E. A. Dare, K. Keratithamkul, B. M. Hiwatig, and F. Li, "Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education," *Education Sciences*, vol. 11, no. 11, 737, 2021. doi: 10.3390/educsci11110737

[24] F. Mufit, Festiyed, A. Fauzan, and Lufri, "The effect of Cognitive Conflict-Based Learning (CCBL) Model on remediation of misconceptions," *Journal of Turkish Science Education*, vol. 20, no. 1, pp. 26–49, 2023. doi: 10.36681/tused.2023.003

[25] S. Dargan, S. Bansal, M. Kumar, A. Mittal, and K. Kumar, "Augmented reality: A comprehensive review," archives of computational methods in engineering," *Archives of Computational Methods in Engineering*, vol. 30, no. 2, pp. 1057–1080, 2023. doi: 10.1007/s11831-022-09831-7

[26] K. S. Kacmaz and C. Kaçmaz, "Bibliometric analysis of research in pediatrics related to virtual and augmented reality: A systematic review," *Current Pediatric Reviews*, vol. 20, no. 2, pp. 178–187, 2024,

doi: 10.2174/1573396319666230214103103
[27] D. J. Borgohain, D. A. Bhanage, M. K. Verma, and A. V. Pawar, "Global research trends in augmented reality: Scientometric mapping based on Scopus database," *Information Discovery and Delivery*, vol. 50, no. 4, pp. 387–403, 2022. doi: 10.1108/idd-08-2021-0081
[28] V. Gopalan, J. A. A. Bakar, and A. N. Zulkifli, "Systematic literature review on critical success factors in implementing augmented reality for science learning environment (2006–2021)," *Education and Information Technologies*, vol. 28, no. 9, pp. 11117–11144, 2023. doi: 10.1007/s10639-023-11613-y
[29] F. Mufit, A. Asrizal, R. Puspitasari, and A. Annisa, "Cognitive conflict-based e-book with real experiment video analysis integration to enhance conceptual understanding of motion kinematics," *Jurnal Pendidikan IPA Indonesia [Indonesian Science Education Journal]*, vol. 11, no. 4, 2022. doi: 10.15294/jpii.v11i4.39333
[30] A. Asrizal, N. Annisa, F. Festiyed, H. Ashel, and R. Amnah, "STEM-integrated physics digital teaching material to develop conceptual understanding and new literacy of students," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 19, no. 7, em2289, 2023. doi: 10.29333/ejmste/13275
[31] X. Zhao, Y. Ren, and K. S. L. Cheah, "Leading Virtual Reality (VR) and Augmented Reality (AR) in education: Bibliometric and content analysis from the web of science (2018–2022)," *SAGE Open*, 2023. doi: 10.1177/21582440231190821
[32] Y. C. Chiang and S. C. Liu, "The effects of extended reality technologies in stem education on students' learning response and performance," *Journal of Baltic Science Education*, 2023. doi: 10.33225/jbse/23.22.568
[33] S. Mohamad Hasim, R. Rosli, L. Halim, M. M. Capraro, and R. M. Capraro, "STEM professional development activities and their impact on teacher knowledge and instructional practice," *Mathematics,* vol. 10, no. 7, 1109, Mar. 2022. doi: 10.3390/math10071109
[34] Z. Zhan and S. Niu, "Subject integration and theme evolution of STEM education in K-12 and higher education research," *Humanities and Social Sciences Communications*, vol. 10, no. 1, Nov. 2023. doi: 10.1057/s41599-023-02303-8
[35] S. Li, X. Jiao, S. Cai, and Y. Shen, "Enhancing ar-based learning environments for stem education: A design-based study on design features, kinematics learning and mathematics self-efficacy," *British Journal of Educational Technology*, vol. 56, no. 4, pp. 1438–1462, 2025. doi: 10.1111/bjet.13528
[36] E. R. Ferrari Lagos *et al.*, "The use of apps based on augmented reality as a tool for teaching STEM subjects in compulsory secondary education," *Education in the Knowledge Society*, vol. 26, 2025. doi: 10.14201/eks.30610
[37] X.-M. Wang, D.-D. Yu, X.-H. Yu, G.-J. Hwang, and F. Li, "Impacts of augmented reality-supported STEM education on students' achievement: A meta-analysis of selected SSCI publications from 2010 to 2023," *Education and Information Technologies*, vol. 29, no. 15, pp. 20547–20585, 2024. doi: 10.1007/s10639-024-12641-y
[38] S. Psycharis, K. Sdravopoulou, and E. Botsari, "Augmented reality in STEM education: Mapping out the future," in *Proc. the Learning Ideas Conference*, Springer, 2023, pp. 677–688. doi: 10.1007/978-3-031-41637-8_55
[39] H. Nakamura and Y. Mizuno, "Development of augmented-reality-based magnetic field visualization system as an educational tool," *Sensors*, vol. 22, no. 20, 8026, 2022. doi: 10.3390/s22208026
[40] J. Kalemkuş and F. Kalemkuş, "Effect of the use of augmented reality applications on academic achievement of student in science education: Meta analysis review," *Interactive Learning Environments*, vol. 31, no. 9, pp. 6017–6034, 2023. doi: 10.1080/10494820.2022.2027458
[41] L. R. Rondon Pereira, C. Maciel, and I. R. Guzman, "Women's academic leadership in STEM: A systematic literature review on challenges, opportunities and strategies," *Studies in Higher Education*, pp. 1–14, 2025. doi: 10.1080/03075079.2025.2511825
[42] S. Verdugo-Castro, A. García-Holgado, and M. C. Sánchez-Gómez, "The gender gap in higher STEM studies: A systematic literature review," *Heliyon*, vol. 8, no. 8, 2022, doi: 10.1016/j.heliyon.2022.e10300
[43] N. Asitah *et al.*, "Educational innovation using augmented reality: Systematic literature review," in *Proc. International Conference on Intelligent Systems and Sustainable Computing*, Springer, 2023, pp. 71–80. doi: 10.1007/978-981-99-4717-1_7
[44] M. Fang, A. Jandigulov, Z. Snezhko, L. Volkov, and O. Dudnik, "New technologies in educational solutions in the field of STEM: The use of online communication services to manage teamwork in project-based learning activities," *International Journal of Emerging Technologies in Learning*, vol. 16, no. 24, pp. 4–22, Dec. 2021. doi: 10.3991/ijet.v16i24.25227
[45] M. Dhanil and F. Mufit, "Augmented reality with the cognitive conflict model: What is effective for improving students' scientific literacy of dynamic fluid material?" *International Journal of Online and Biomedical Engineering*, vol. 21, no. 3, 2025. doi: 10.3991/ijoe.v21i03.53051
[46] F. Mufit, Y. Hendriyani, Usmeldi, M. Dhanil, and M. R. Tanjung, "The effectiveness of smartphone-based interactive multimedia integrated cognitive conflict models to improve 21st-century skills," *International Journal of Information and Education Technology*, vol. 13, no. 11, pp. 1793–1801, 2023. doi: 10.18178/ijiet.2023.13.11.1991
[47] M. Hayati and F. Mufit, "Needs analysis of cognitive conflict teaching materials integrated with augmented reality global warming material," *Physics Learning and Education*, vol. 1, no. 4, pp. 204–210, 2023. doi: 10.24036/ple.v1i4.55
[48] A. Akmam, R. Hidayat, F. Mufit, N. Jalinus, and A. Amran, "Need analysis to develop a generative learning model with a cognitive conflict strategy oriented to creative thinking in the computational physics course," *Journal of Physics: Conference Series*, vol. 2309, no. 1, 12095, 2022. doi: 10.1088/1742-6596/2309/1/012095
[49] R. H. Ennis. (2011). The nature of critical thinking: An outline of critical thinking dispositions and abilities. University of Illinois. [Online]. *2(4)*. pp. 1–8. Available: https://education.illinois.edu/docs/default-source/faculty-documents/robert-ennis/thenatureofcriticalthinking_51711_000.pdf
[50] R. H. Ennis, "Critical thinking: A streamlined conception," *The Palgrave Handbook of Critical Thinking in Higher Education*, Springer, 2015, pp. 31–47. doi: 10.1057/9781137378057_2
[51] P. A. Facione and N. C. Facione, "Critical thinking for life," *Inquiry: Critical Thinking across the Disciplines*, vol. 28, no. 1, pp. 5–25, 2013, doi: 10.5840/inquiryct20132812
[52] B. Thornhill-Miller *et al.*, "Creativity, critical thinking, communication, and collaboration: Assessment, certification, and promotion of 21st century skills for the future of work and education," *Journal of Intelligence*, vol. 11, no. 3, 54, 2023. doi: 10.3390/jintelligence11030054
[53] X. Ma, Y. Zhang, and X. Luo, "Students' and teachers' critical thinking in science education: Are they related to each other and with physics achievement?" *Research in Science and Technological Education*, vol. 41, no. 2, pp. 734–758, 2023. doi: 10.1080/02635143.2021.1944078
[54] I. H. Wenno, A. Limba, and Y. G. M. Silahoy, "The development of physics learning tools to improve critical thinking skills," *International Journal of Evaluation and Research in Education*, vol. 11, no. 2, 862, 2022. doi: 10.11591/ijere.v11i2.21621
[55] N. Mafarja, H. Zulnaidi, and H. M. Fadzil, "Using reciprocal teaching strategy to improve physics students' critical thinking ability," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 18, no. 1, em2069, 2022. doi: 10.29333/ejmste/11506
[56] S. McKenney and T. C. Reeves, "Educational design research: Portraying, conducting, and enhancing productive scholarship," *Medical Education*, vol. 55, no. 1, pp. 82–92, 2021. doi: 10.1111/medu.14280
[57] S. Tobón and J. Luna-Nemecio, "Complex thinking and sustainable social development: Validity and reliability of the complex-21 scale," *Sustainability*, vol. 13, no. 12, p. 6591, 2021, doi: 10.3390/su13126591
[58] T. A. Sondergeld and C. C. Johnson, "Development and validation of a 21st century skills assessment: Using an iterative multimethod approach," *School Science and Mathematics*, vol. 119, no. 6, pp. 312–326, 2019. doi: 10.1111/ssm.12355
[59] P. Reddy, K. Chaudhary, B. Sharma, and S. Hussein, "Essaying the design, development and validation processes of a new digital literacy scale," *Online Information Review*, vol. 47, no. 2, pp. 371–397, 2023, doi: 10.1108/OIR-10-2021-0532
[60] K. Tan and X. S. Chen, "Keeping up with technology: Socioemotional and equity challenges with children and schools," *Children and Schools*, vol. 45, no. 3, pp. 127–130, 2023. doi: 10.1093/cs/cdad014
[61] F. Amlasri, "Simulations to teach science subjects: Connections among students; engagement, self-confidence, satisfaction, and learning styles," *Education and Information Technologies*, vol. 27, no. 5, pp. 7161–7181, 2022. doi: 10.1007/s10639-022-10940-w
[62] M. Hafeez, "Systematic review on modern learning approaches, critical thinking skills and students learning outcomes," *Indonesian Journal of Educational Research and Review*, vol. 4, no. 1, pp. 167–178, 2021. doi: 10.23887/ijerr.v4i1.33192
[63] D. M. Anggraeni, B. K. Prahani, N. Suprapto, N. Shofiyah, and B. Jatmiko, "Systematic review of problem based learning research in fostering critical thinking skills," *Thinking Skills and Creativity*, vol. 49, 101334, 2023. doi: 10.1016/j.tsc.2023.101334
[64] F. Mufit, Y. Hendriyani, and M. Dhanil, "Design Immersive Virtual Reality (IVR) with cognitive conflict to support practical learning of quantum physics," *Journal of Turkish Science Education*, vol. 21, no. 2,

pp. 369–388, 2024. doi: 10.36681/tused.2024.020.
[65] P. Pečiuliauskienė, "Instructional clarity in physics lessons: Students' motivation and self-confidence," *Cogent Education*, vol. 10, no. 2, 2236463, 2023. doi: 10.1080/2331186X.2023.2236463
[66] Z. Mengmeng, H. Xiao, L. Xiangwei, and L. Linying, "Effects of augmented reality-based digital mobile game-based learning on the engagement of students.," *International Journal of Interactive Mobile Technologies*, vol. 19, no. 6, 2025. doi: 10.1080/21548455.2022.2072015
[67] H. Akram, A. H. Abdelrady, A. S. Al-Adwan, and M. Ramzan, "Teachers' perceptions of technology integration in teaching-learning practices: A systematic review," *Frontiers in Psychology*, vol. 13, 920317, 2022. doi: 10.3389/fpsyg.2022.920317
[68] S. O'Connor and H. Liu, "Gender bias perpetuation and mitigation in AI technologies: Challenges and opportunities," *AI & SOCIETY*, vol. 39, no. 4, pp. 2045–2057, 2024. doi: 10.1007/s00146-023-01675-4
[69] S. Timotheou *et al.*, "Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review," *Education and Information Technologies*, vol. 28, no. 6, pp. 6695–6726, 2023. doi: 10.1007/s10639-022-11431-8
[70] J. Wang, D. E. H. Tigelaar, T. Zhou, and W. Admiraal, "The effects of mobile technology usage on cognitive, affective, and behavioural learning outcomes in primary and secondary education: A systematic review with meta-analysis," *Journal of Computer Assisted Learning*, vol. 39, no. 2, pp. 301–328, 2023. doi: 10.1111/jcal.12759
[71] H.-Y. Lee, Y.-P. Cheng, W.-S. Wang, C.-J. Lin, and Y.-M. Huang, "Exploring the learning process and effectiveness of STEM education via learning behavior analysis and the interactive-constructive-active-passive framework," *Journal of Educational Computing Research*, vol. 61, no. 5, pp. 951–976, 2023. doi: 10.1177/07356331221136888
[72] M. Sırakaya and D. Alsancak Sırakaya, "Augmented reality in STEM education: A systematic review," *Interactive Learning Environments*, vol. 30, no. 8, pp. 1556–1569, 2022. doi: 10.1080/10494820.2020.1722713
[73] K. M. Murphy and N. C. Kelp, "Undergraduate STEM students' science communication skills, science identity, and science self-efficacy influence their motivations and behaviors in STEM community engagement," *Journal of Microbiology and Biology Education*, vol. 24, no. 1, e00182-22, 2023. doi: 10.1128/jmbe.00182-22
[74] I. Pont-Niclòs, A. Martín-Ezpeleta, and Y. Echegoyen-Sanz, "Scientific creativity in secondary students and its relationship with STEM-related attitudes, engagement and work intentions," *Frontiers in Education*, vol. 9, no. July, pp. 1–13, 2024. doi: 10.3389/feduc.2024.1382541.
[75] H. M. Kyed, *Inside the Police Stations in Maputo City*, Oxford Scholarship Online, Oxford University Press, 2017. doi: 10.1093/oso/9780190676636.003.0014
[76] Y. A. Alkhabra, U. M. Ibrahem, and S. A. Alkhabra, "Augmented reality technology in enhancing learning retention and critical thinking according to STEAM program," *Humanities and Social Sciences Communications,* vol. 10, no. 1, Apr. 2023. doi: 10.1057/s41599-023-01650-w
[77] S. Gao, Y. Lu, C. H. Ooi, Y. Cai, and P. Gunawan, "Designing interactive augmented reality application for student's directed learning of continuous distillation process," *Computers and Chemical Engineering*, vol. 169, 108086, 2023. doi: 10.1016/j.compchemeng.2022.108086
[78] Y. Cheng, M. H. Lee, C. S. Yang, and P. Y. Wu, "Hands-on interaction in the Augmented Reality (AR) chemistry laboratories enhances the learning effects of low-achieving students: A pilot study," *Interactive Technology and Smart Education,* vol. 21, no. 1, pp. 44–66, Sep. 2022. doi: 10.1108/itse-04-2022-0045
[79] I. P. Dewi *et al.*, "How effective is immersive AR continental food course for vocational education? analyzing knowledge gains and learning outcome effects," *International Journal of Information and Education Technology*, vol. 15, no. 1, 2025. doi: 10.18178/ijiet.2025.15.1.2225
[80] A. D. Samala, I. P. Dewi, and L. Mursyida, " E-labsheet project' 4cs-based supplementary media for flexible learning: Is it well implemented?" *International Journal of Online and Biomedical Engineering*, vol. 19, no. 1, 2023. doi: 10.3991/ijoe.v19i01.35523
[81] R. E. Balcita and T. D. Palaoag, "Augmented reality model framework for maritime education to alleviate the factors affecting learning experience," *International Journal of Information and Education Technology*, vol. 10, no. 8, pp. 603–607, 2020. doi: 10.18178/ijiet.2020.10.8.1431
[82] F. Novitra, Festiyed, Yohandri, and Asrizal, "Development of online-based inquiry learning model to improve 21st-century skills of physics students in senior high school," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 17, no. 9, pp. 1–20, 2021. doi: 10.29333/ejmste/11152
[83] Festiyed, F. Novitra, Yohandri, and Asrizal, "Networked-based inquiry: An effective physics learning in the new normal covid-19 era in Indonesia," *International Journal of Instruction*, vol. 15, no. 2, pp. 997–1016, 2022. doi: 10.29333/iji.2022.15255a

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