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presents a series of scientific articles resulting from collaborative research between academics from various national and international universities, particularly from Malaysia and Japan. This edition focuses on educational transformation through educational technology and instructional innovation at the elementary, secondary, and vocational levels, exploring diverse strategies such as learning media innovation, e-learning, innovative instructional design, and digital learning evaluation, summarized in several pillars of innovation.



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We are proud to present the first issue of 2026 for the Indonesian Journal of Learning and Instructional Innovation (Vol. 4, No. 01, June 2026). This edition marks a significant milestone in our publication's history, featuring a series of scientific articles born from cross-border research collaborations between academics from various national and international universities, with a particular emphasis on partnerships with institutions in Malaysia and Japan. By bringing together diverse perspectives and global expertise, this issue highlights the power of international synergy in addressing the evolving challenges of the modern classroom.

The contributions within this volume focus on the fundamental pillars of educational transformation, specifically examining how educational technology and instructional innovation can be harnessed to elevate teaching and learning standards. The research presented here spans the critical developmental and professional stages of elementary, secondary, and vocational education. Each article explores nuanced, future-oriented strategies designed to improve learning quality, ranging from learning media innovation and e-learning implementations to innovative instructional designs and digital learning evaluations. By synthesizing global academic insights with practical applications, this edition provides a comprehensive roadmap for educators and policymakers alike, underscoring that the future of education lies in the continuous pursuit of innovation and the strengthening of international ties.



Developing a Virtual Museum Tour as a History Learning Medium for Junior High Schools

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ABSTRACT

History instruction at the junior secondary school level remains predominantly teacher-centered and expository, limiting students' active engagement and conceptual understanding. This study aims to develop a Virtual Museum Tour-based learning media using the Lapentor platform for seventh-grade prehistory materials and to examine its feasibility through expert validation. The research employed a Research and Development (R&D) approach based on the Alessi & Trollip development model, which consists of planning, design, and development stages. The research participants were seventh-grade students of SMP Widya Wacana 1 Surakarta. Data were collected through observation, interviews, documentation, and validation questionnaires administered to media and subject-matter experts. The results indicate that the Virtual Museum Tour media, designed in accordance with the Cognitive Theory of Multimedia Learning proposed by Richard E. Mayer, meets the feasibility criteria in terms of content accuracy, visual design, navigation, and multimedia integration. The developed product was deemed valid and suitable for use as a visual-interactive alternative in history instruction.

Keywords: *Virtual Museum Tour, History Learning, Multimedia, Lapentor, Media Development.*



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INTRODUCTION

History education at the Junior High School (SMP) level plays a strategic role in shaping historical consciousness, national identity, and students' critical thinking skills. History does not merely present a chronology of past events; it builds interpretative and reflective capabilities regarding social and cultural dynamics. Effective history education should develop conceptual understanding, analytical skills, and a sense of values relevant to contemporary life (Karlsson, 2020; Oppong et al., 2022).

However, the practice of history education in schools still faces several structural problems. Learning tends to be oriented toward delivering factual information through lectures and textbooks, failing to provide contextual and exploratory learning experiences. This condition results in low learning motivation and passive student participation (Simbolon, 2023; Sugiarto & Musyafa, 2024). Preliminary observations conducted through interviews with a history teacher and questionnaires administered to 50 seventh-grade students at SMP Widya Wacana 1 Surakarta further confirmed these challenges. Although 84% of students expressed positive attitudes toward history (22% strongly liked and 62% liked the subject), classroom instruction was still dominated by conventional media, particularly textbooks (78%) and PowerPoint presentations (86%). Moreover, 74% of students perceived history learning as primarily

memorization-oriented, while 20% reported that the limited availability of supporting learning media hindered their understanding of the material. Although 76% of students reported being interested during lessons, only 6% felt highly engaged throughout the learning process. In contrast, 98% of respondents stated that they understood historical content more easily through visual and interactive media, and all students (100%) expressed a preference for virtual learning media such as a Virtual Museum Tour. These findings reveal a clear mismatch between current instructional practices and students' learning preferences, highlighting the urgent need for more interactive and visually engaging learning media.

This problem becomes even more pronounced when contrasted with the characteristics of the digital generation, who are accustomed to visual interaction and multimedia-based technology. The digital transformation in education has shifted the learning paradigm from teacher-centered to student-centered learning, emphasizing interactivity, personalization, and immersive learning experiences (Karanth et al., 2024). The integration of digital technology is proven to enhance engagement and learning effectiveness when designed pedagogically and systematically (Malysheva et al., 2022).

Various studies show that the use of interactive media in history education can improve student interest and understanding. Interactive video media based on digital platforms like Edpuzzle has proven effective in helping students understand abstract historical concepts (Purmintasari & Lesmana, 2023). The use of image-based visuals and animations can also strengthen the connection between new knowledge and students' prior knowledge (Zikriyah Amaliyah & Yanto, 2022). Furthermore, digital exploration of historical sites allows students to gain contextual experiences without needing to conduct physical site visits (Nikmah & Pamungkas, 2022).

In this context, the concept of a Virtual Museum Tour emerges as a relevant innovation. A Virtual Museum Tour allows students to explore exhibition spaces digitally through 360-degree visualizations, interactive hotspot features, and the integration of text, audio, and video. This medium has the potential to provide a more concrete spatial learning experience while encouraging independent exploration and inquiry-based learning.

Theoretically, the effectiveness of multimedia-based media is supported by Richard E. Mayer's Multimedia Learning Theory (2014), which states that learning is more effective when information is presented through integrated visual and auditory channels. The principles of dual-channel, limited capacity, and active processing emphasize the importance of media design that avoids cognitive overload and optimizes information integration. Thus, the development of a Virtual Museum Tour must not only focus on visual aesthetics but must also be grounded in a strong cognitive foundation.

This research utilizes the development model by Alessi & Trollip, which emphasizes continuous evaluation at every stage of multimedia product development. This model was chosen because it provides a systematic framework for integrating planning, design, and development aspects iteratively.

While research regarding digital media in history education is extensive, most studies still focus on interactive videos or quiz-based applications. There has been limited development of spatial exploration media utilizing structured virtual tour technology for prehistoric material at the SMP level. Additionally, research that explicitly integrates Multimedia Learning Theory principles into the design of a Virtual Museum Tour remains scarce, particularly within the context of Indonesian history education.

Based on the literature review and the preliminary needs analysis, there is a clear gap between the increasing demand for contextual, interactive history learning and the conventional instructional practices currently implemented in schools. While students demonstrate a strong interest in history and express a clear preference for visual and immersive learning experiences, the instructional media used remain predominantly text-based and teacher-centered. Furthermore, previous studies have mainly focused on interactive videos or quiz-based applications, with limited attention given to spatial exploration media utilizing Virtual Museum Tour technology for prehistoric learning at the junior high school level. In addition, studies integrating Mayer's Multimedia Learning Theory into the design of Virtual Museum Tour media

are still scarce, particularly within the context of Indonesian history education. Therefore, this study aims to develop a Lapentor-based Virtual Museum Tour for seventh-grade prehistoric history learning and to evaluate its feasibility through expert validation. The proposed learning media is expected to contribute both practically to history learning innovation and theoretically to the advancement of interactive multimedia-based educational technology.

METHODS

This study employed a Research and Development (R&D) approach using the instructional multimedia development model proposed by Alessi and Trollip (2001). The model was selected because it provides a systematic and iterative framework for designing, developing, and evaluating interactive multimedia learning products. Unlike conventional development models, Alessi and Trollip emphasize continuous evaluation and revision throughout every stage of the development process, ensuring that the resulting product aligns with instructional objectives and users' needs. Given these characteristics, the model is particularly suitable for developing a Virtual Museum Tour, which integrates various multimedia elements and user interaction within a digital learning environment.

The development process consisted of three main phases: planning, design, and development. During the planning phase, a needs analysis was conducted through classroom observations, interviews with the history teacher, and questionnaires administered to seventh-grade students to identify instructional problems and learner characteristics. The design phase involved formulating learning objectives, developing storyboards, designing the navigation structure and user interface, and organizing multimedia content based on the principles of Mayer's Multimedia Learning Theory. In the development phase, the Virtual Museum Tour was developed using the Lapentor platform by integrating various multimedia components. The completed product then underwent alpha testing through validation by subject matter experts and media experts, followed by revisions based on expert feedback. Subsequently, beta testing was conducted with students to evaluate the practicality of the learning media. Continuous evaluation throughout each phase ensured that the developed learning media met the criteria of validity and practicality before being implemented in the learning process.

Research Subjects and Location

The research was conducted at SMP Widya Wacana 1 Surakarta. The research subjects consist of:

1. Needs Analysis Subjects: Social Studies (IPS) teachers and 7th-grade students.
2. Small-scale Trial Subjects: 22 7th-grade students selected using a simple random sampling technique. Simple random sampling was utilized to provide every member of the population an equal opportunity to be sampled, thereby minimizing selection bias (Noor et al., 2022).

Validators were selected using a purposive sampling technique, considering academic qualifications (minimum Master's degree), professional experience, and relevance of expertise (Guinovart-Pedescoll & Palau, 2025). The Expert Validators consist of:

1. Two content experts (History/Social Studies Education).
2. Two media experts (Educational Technology/Information Technology and Computer Engineering).

Development Procedures

1. Planning Phase This stage aims to identify learning needs and establish product specifications. Activities include:
 - a. Curriculum analysis for Social Studies (IPS) Phase D.
 - b. Observation of the learning process.
 - c. Teacher interviews.
 - d. Distribution of student needs analysis questionnaires.

- e. Analysis of learner characteristics. Needs analysis is conducted to ensure that the developed product is based on real problems (needs-based development) rather than technology innovation without a pedagogical foundation.
2. Design Phase The design phase includes:
 - a. Developing navigation flowcharts.
 - b. Creating storyboards.
 - c. Designing the User Interface (UI).
 - d. Drafting content scripts and audio narration.
 - e. Designing evaluation instruments (quizzes). Media design refers to Richard E. Mayer's Cognitive Theory of Multimedia Learning, which emphasizes the integration of visual and auditory channels, information segmentation, and cognitive load reduction (Mayer, 2014). Principles such as the multimedia, coherence, signalling, and modality principles are applied to ensure the media is not only visually appealing but also cognitively effective.
 3. Development Phase This stage involves implementing the design into a tangible product. Activities include:
 - a. Developing the landing page using HTML and CSS.
 - b. Integrating 360° panoramas using the Lapentor platform.
 - c. Creating interactive hotspots.
 - d. Producing audio narration and videos.
 - e. Integrating all multimedia components. The resulting product is a web-based Virtual Museum Tour accessible via students' digital devices.

Data Collection Techniques

Data were collected using the following techniques:

1. Observation: Used to identify the condition of history learning prior to media development.
2. Interviews: Conducted with Social Studies teachers to gather information regarding teaching methods, constraints, and the need for innovative media.
3. Questionnaires: Used during the student needs analysis, media expert validation, and content expert validation stages. The validation instrument uses a 4-point Likert scale to avoid neutral choices and increase the decisiveness of the assessment.

Data Analysis Techniques

Data were analyzed using descriptive quantitative analysis. The validation scores were calculated using the following formula:

$$Percentage = \frac{Obtained\ Score}{Maximum\ Score} \times 100\%$$

The resulting percentages were then converted into feasibility categories categories as in table 1. The category were adapted from the instructional media feasibility conversion standards.

Table 1. Feasibility categories

Percentage	Category
81–100%	Highly Feasible
61–80%	Feasible
41–60%	Moderately Feasible
≤40%	Not Feasible

RESULTS AND DISCUSSION

Results

1. Product Development Results

The developed product is a Virtual Museum Tour based on the Lapentor platform, which includes: (a) an HTML and CSS-based landing page; (b) 10 interactive hotspots containing prehistoric material; (c) integrated 360° panoramas; (d) audio narration at specific points of interest; (e) supporting educational videos; and (f) an evaluation quiz integrated via Google Forms. The media's navigation structure was designed using a flowchart as a developmental guide. The navigation flow of the media can be seen in Figure 1.

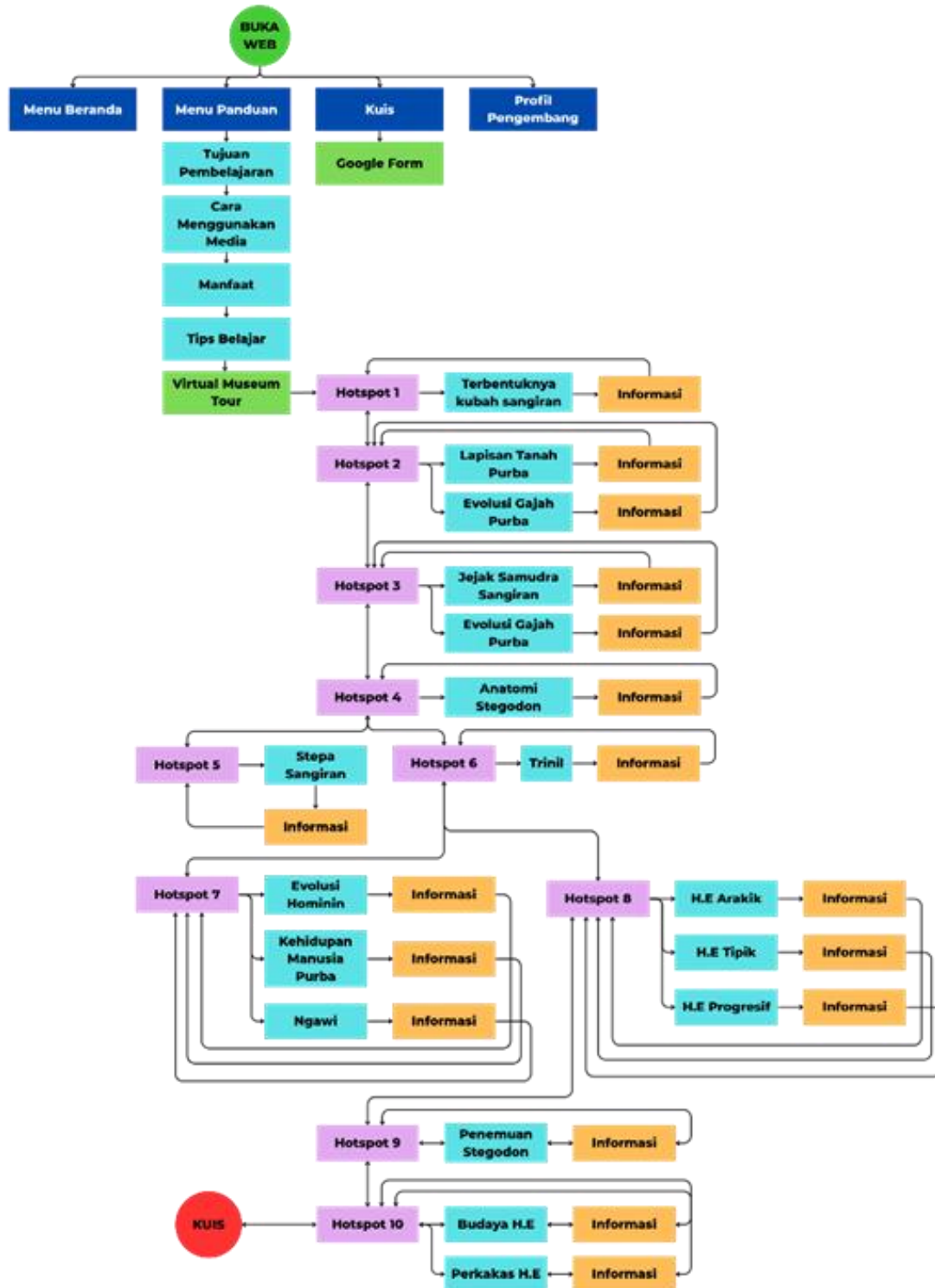


Figure 1. Flowchart

Then, as shown in Figure 2, the media flow begins with the landing page, followed by the exploration of the virtual space, and concludes with a final evaluation. Subsequently, a storyboard was developed to visualize every media interface in detail. The design of the initial landing page storyboard is shown in Figure 2.



Figure 2. Landing Page Interface

The content interface of the Virtual Museum Tour based on 360° panoramas can be seen in Figure 3. As illustrated in Figure 3, students can explore historical objects through interactive hotspot features integrated with text and audio narration.



Figure 3. Virtual Museum Tour Content

2. Expert Validation Results

a. Content Expert Validation

Content validation was conducted to assess the alignment of content with the curriculum, historical factual accuracy, depth of material, and learning benefits. The recapitulation of the content expert validation results is presented in Table 2.

Table 2. Content Expert Validation Results

No	Aspect	Evaluation Criteria	Expert	
			1	2
1.	Content	1. Is the presented material aligned with the Grade VII Social Studies Basic Competencies?	3	5
		2. Are the historical facts presented accurate and reliable?	5	5
		3. Is the depth of the material appropriate for the cognitive development of junior high school students?	4	5
		4. Is the sequence of material presentation logical and systematic, making it easy to understand?	4	5
		5. Is the material supported by visual elements that help students understand the historical content?	4	5
2.	Benefits	1. Does the Virtual Museum Tour medium provide a new and distinct learning experience for students?	5	5

No	Aspect	Evaluation Criteria	Expert	
			1	2
		2. Does the medium help students understand historical material more quickly and effectively?	5	4
		3. Does the medium have the potential to improve students' comprehension of historical material?	5	4
Total			35	38
Average			4,37	4,73

Based on Table 2, the media was declared feasible with minor revisions regarding the simplification of audio narration and the strengthening of conceptual integration.

b. Media Expert Validation

Media expert validation covered visual aspects, navigation, interactivity, audio, and technical systems. The recapitulation of the media expert validation results is presented in Table 3.

Table 3. Media Expert Validation Results

No.	Aspect	Evaluation Criteria	Expert	
			1	2
1	Visual Design	1. Does the learning media present a combination of images (360° panoramas, artifacts) and explanatory text that complement each other to facilitate students' understanding? (<i>Multimedia Principle</i>)	5	5
		2. Does the media avoid irrelevant visual elements (e.g., excessive decorations or distracting animations) that may interfere with students' learning focus? (<i>Coherence Principle</i>)	5	4
		3. Is the descriptive text positioned close to the corresponding visual objects to help students easily associate the information? (<i>Spatial Contiguity Principle</i>)	5	4
		4. Does the media include visual cues (e.g., highlights, icons, or color coding) to emphasize important information? (<i>Signaling Principle</i>)	4	5
2	Text	1. Is the textual information presented concisely without unnecessary repetition when audio narration is already provided? (<i>Redundancy Principle</i>)	5	5
		2. Is the language used conversational and learner-friendly rather than overly formal or rigid? (<i>Personalization Principle</i>)	4	5
3	Content	1. Is the historical content organized logically and sequentially according to the conceptual structure of the topic?	5	4
		2. Are students provided with introductory explanations of historical terms and concepts before beginning the exploration? (<i>Pre-training Principle</i>)	4	4
4	Audio	1. Is the learning material presented in manageable segments (rooms/topics) to reduce students' cognitive load? (<i>Segmenting Principle</i>)	4	4

No.	Aspect	Evaluation Criteria	Expert	
			1	2
		2. Is the audio narration presented simultaneously with the corresponding visual content? (<i>Temporal Contiguity Principle</i>)	5	5
		3. Does the audio (including background music) avoid interfering with students' processing of the primary instructional content? (<i>Coherence Principle</i>)	5	4
5	Navigation	1. Does the media provide learners with control over the sequence of exploration according to their learning needs? (<i>Segmenting Principle & Learner Control</i>)	5	5
		2. Does the navigation help students move clearly and systematically between learning segments or topics? (<i>Segmenting Principle</i>)	5	4
6	Interactivity	1. Do interactive features (e.g., hotspots and clickable objects) encourage students to connect visual information with explanatory content? (<i>Multimedia Principle & Active Processing</i>)	5	4
		2. Does the interactivity enable students to actively engage in learning rather than passively viewing the content? (<i>Generative Processing – Mayer's CTML</i>)	5	4
7	Technical Quality	1. Does the media operate reliably without technical issues that may disrupt students' concentration during learning? (<i>Low Cognitive Load</i>)	5	5
		2. Can the media be accessed smoothly across different devices without reducing the quality of the learning experience? (<i>Low Cognitive Load</i>)	4	4
		3. Does the system respond quickly enough to avoid interrupting students' information processing? (<i>Low Cognitive Load</i>)	5	5
Total			85	80
Average			4.72	4.40

As shown in Table 3, the media achieved a feasible category for use, with minor improvements needed to optimize the integration of text and audio.

Discussion

The development of the Lapentor-based Virtual Museum Tour by Hidayatullah et al. demonstrates a structural transformation in history education from a teacher-centered paradigm to an active, learner-centered exploration. Historically, traditional multimedia integration in classrooms was heavily constrained by technological limitations, often restricting student interaction to basic text and sound elements (Setyaningsih, 2023). However, contemporary shifts in educational technology have allowed multimedia to incorporate complete text, graphics, animation, images, and audio-visual streams that easily cross regional and national boundaries to provide rich learning resources (Setyaningsih, 2023). This rapid pedagogical evolution underpins the immersive design of the Virtual Museum Tour, where interactive variations in teaching styles, digital media, and student-teacher interactions are

deliberately deployed to break classroom monotony, overcome learning boredom, and adjust to diverse learning styles (Arifin et al., 2025).

From an instructional design perspective, the systematic planning of this virtual tour echoes the rigor found in modern Research and Development (R&D) frameworks. Multimedia systems developed through systematic instructional design models are highly effective in ensuring that interactive digital tools are delivery-capable, multimodal, and adaptive (Yasni et al., 2025). This structured approach is further optimized when digital instructional strategies emphasize organized, comprehensive learning management rather than relying on sheer content transmission alone, which significantly supports higher-order cognitive processes (Sasongko et al., 2025). Furthermore, the pedagogical impact of this digital tour is greatly augmented when educators explicitly identify and accommodate students' baseline capabilities. Integrating problem-based instructional models paired with differentiated approaches helps teachers build a more interactive and motivating environment that actively enhances student participation and independent task completion (Pawitra et al., 2025).

The integration of 360-degree interactive panoramas in this study also functions as a vital extension of educational technology's role in establishing adaptive learning spaces. The modern turn toward digital-centric instruction, accelerated by systemic transitions from face-to-face settings to screen-to-screen modalities, places a high demand on educators to master technology, select suitable platforms, and design media that match the precise needs and characters of digital learners (Peramtasari, 2023). This technological shift is visible across multiple educational domains. For example, the application of cloud-computing platforms to manage student responses and evaluations has markedly increased classroom efficiency and the quality of learning outcomes (Purnama et al., 2024). Similarly, the utilization of direct, hands-on media within structured collaborative frameworks has proven successful in increasing student understanding and improving classical learning completeness (Fitriani & Ridhani, 2025). Furthermore, directing students to engage effectively with digital technology, understand software functions, and solve technical problems ensures that learners build necessary proficiencies aligned with the demands of the modern digital era (Vitariyanti et al., 2024).

The effectiveness of this Virtual Museum Tour is deeply anchored in Cognitive Theory of Multimedia Learning (CTML), where principles such as the segmenting, signaling, and spatial contiguity principles are applied to ensure the media is cognitively effective. This deliberate cognitive balancing is essential because contemporary educational research warns that while immersive, 3D digital environments offer revolutionary communication and training opportunities, they carry an inherent risk of cognitive overload if the emerging technology is not designed with a strong pedagogical foundation (Alhakimi, 2023). To prevent such overload and truly optimize learning outcomes, digital media must be paired with explicit metacognitive support. True metacognition requires students to maintain active awareness and control over their cognitive regulation, including planning, monitoring, and evaluation (Buwono et al., 2025). When digital environments are designed systematically around authentic, interactive elements, they successfully drive student motivation, build logical thinking, and reinforce active problem-solving skills (Raziana & Wibawanto, 2025).

Crucially, the success of these interactive digital spaces depends on the holistic integration of cognitive, social, and emotional development. Structured multimedia strategies are vital to increasing learner involvement, improving cognitive and emotional abilities, and creating a pleasant learning atmosphere (Nongko et al., 2025). These digital-age educational practices must also recognize that informal paths given throughout a learner's environment form the essential foundation that shapes lifelong habits, character, and behavior (Pinilih, 2023). Therefore, classroom teachers must continue this trajectory by serving as critical emotional anchors and positive role models (Septyventia et al., 2024). By creating a safe, supportive classroom environment and integrating character values directly into the curriculum, educators can help students build healthy relationships, increase empathy, and manage conflict well during digital exploration (Septyventia et al., 2024).

Theoretical implications indicate that incorporating the Cognitive Theory of Multimedia Learning into digital exploration media can mitigate text-heavy cognitive load. Practically,

shifting from conventional teacher-centered expository methods to interactive visual technologies can significantly increase students' situational interest, engagement, and motivation to learn abstract historical concepts.

CONCLUSION

This research successfully developed a Virtual Museum Tour learning medium that is declared feasible for use based on expert validation in both content and media. Developed from a needs analysis highlighting the demand for more visual, interactive, and contextual history education, the media integrates 360° panoramas, interactive hotspots, and audio narration in alignment with Richard E. Mayer's multimedia learning principles. However, as this study was limited to the development and feasibility stages, the empirical impact on learning outcomes remains untested. Consequently, future research should employ robust experimental designs to evaluate its effects on conceptual understanding and cognitive load, while teachers are encouraged to practically integrate this tool into guided pedagogical strategies to ensure meaningful student exploration. It is highly recommended to transition from the feasibility validation phase into robust experimental research designs to empirically measure the media's direct impact on students' conceptual understanding, spatial retention, creative thinking indicators.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this research. This study was conducted independently, and the author have no financial or personal relationships with individuals or organizations that could inappropriately influence or bias the content of this work.

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Teaching Factory-Based Learning Majoring in Machining Engineering at Vocational High School

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ABSTRACT

This study aims to analyze the effectiveness of the Teaching Factory (TEFA)-based learning model in improving the competence of machining engineering students at a vocational high school. It focuses on identifying differences in learning outcomes between students taught using TEFA integrated with industry standards and those taught using conventional methods. This research is important to ensure curriculum alignment with industry needs and to enhance graduate competitiveness in the Industry 4.0 era. This study employed a quantitative, quasi-experimental design. The population consisted of grade XI machining engineering students at Vocational High School Warga Surakarta, selected using cluster random sampling into experimental and control groups. Data were analyzed using one-way ANOVA. The results showed a significant difference in student competence, with TEFA outperforming conventional methods. TEFA creates a more relevant learning environment, improves discipline, and enhances technical skills in machine operation. These findings indicate that TEFA is effective and should be fully integrated into vocational school curricula.

Keywords: *Machining Engineering, Student Competencies, Teaching Factory*



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INTRODUCTION

Vocational education plays a vital role in the architecture of national economic development, particularly by providing a skilled workforce prepared to adapt to the dynamics of global technological change (Li & Pilz, 2021). Law No. 20 of 2003 concerning the National Education System explicitly states that vocational education aims to prepare students, especially for work in specific fields. However, the reality on the ground reveals a significant gap between the competencies produced by vocational high schools and those required by the Business and Industrial World. Data from the Central Statistics Agency in recent years often shows that vocational school graduates are a significant contributor to the open unemployment rate, indicating a mismatch between labor supply and industrial demand (Entwistle, 2023).

In the context of machining engineering majors, this challenge is becoming increasingly evident as the manufacturing industry transitions to Industry 4.0, characterized by precision,

efficiency, and digitalization (Maganga, 2025). Machining is no longer just about operating a lathe or conventional lathe, but also involves an understanding of quality standards, production time management, occupational safety, and mastery of Computer Numerical Control technology (Yao, 2024). Conventional learning methods, which are teacher-centered and focus solely on achieving curriculum targets without considering industrial production quality standards, are considered outdated (Cahyono et al., 2025). Students often only practice on workpieces that lack a selling point (e.g., exercises on words), so they don't feel the pressure or the authentic work atmosphere.

To overcome these problems, the government, through the Ministry of Education, Culture, Research, and Technology, is intensively encouraging the revitalization of vocational schools by implementing the Teaching Factory learning model (Quinn et al., 2025). The Teaching Factory is a production/service-based learning concept that adheres to industry standards and procedures and is carried out in an atmosphere similar to that of industry (Tri Cahyono et al., 2023). The primary objective is to foster an industrial climate within the school environment, enabling the simultaneous transfer of knowledge and skills and the development of a work ethic. According to the latest study, TEFA is not just a place of practice, but a vehicle for integrating curriculum, human resources, and business-oriented school management (Carroll et al., 2021).

Vocational High School Warga Surakarta, one of the referral vocational schools in Central Java with a strong track record of industry partnerships, recognizes the urgency of implementing this TEFA. As a school focused on the quality of its graduates, the school must ensure that the learning process in the machining workshop provides real-world conditions that simulate actual manufacturing production conditions (Murray et al., 2019). However, implementing TEFA at the education unit level often faces obstacles, including management issues, instructor readiness, and the synchronization of block schedules. Some literature states that TEFA's success is highly dependent on the school's management's commitment and industry partnerships (de Ruiter et al., 2019).

Previous research by Schwab, (2018) has shown that production-based learning increases student motivation; however, it has not specifically measured its significant impact using variance tests on complex machining competencies. Meanwhile, research by Rahmawati and Budi emphasizes the entrepreneurial aspect of TEFA but lacks the technical precision-machining element. There is also a study by Rahman, (2023) that discusses workshop management, but it has not addressed comparisons of learning outcomes using inferential statistics. This is where the research gap that this study aims to fill lies. Most previous studies have been descriptive, qualitative, or simply correlational. This study presents a more robust experimental approach, using ANOVA to demonstrate the method's effectiveness statistically (Polushkina et al., 2025).

The importance of integrating soft skills and hard skills in TEFA learning has also been highlighted in various contemporary literature. In the post-pandemic era, the graduate industry is adaptive. (Tong et al., 2021) stated that vocational education needs to transition from simulation to product realization. In the TEFA model, students are assessed not only on the final result of the workpiece but also on the process of working, which includes machine setup, selection of cutting tools, and quality control. This aligns with Pathak, (2021) opinion that quality assurance is at the heart of TEFA's learning. Without strict quality standards, TEFA will be an ordinary practice that wastes materials.

In the Department of Engineering at Vocational High School Warga Surakarta, the implementation of TEFA is expected to enhance students' competence across various aspects, including reading technical drawings and machine programming to production execution (Eduardo et al., 2023). However, the effectiveness of its application needs to be tested empirically. Whether students involved in the TEFA production line exhibit higher competence compared to those who learn with traditional simulation methods is a crucial question to answer, considering the significant investment required to run it effectively (Zheng et al., 2020).

In addition to the technical aspect, the psychological aspect of learning is also an interesting variable. A structured learning environment, such as a factory, is believed to foster a professional work ethic. (Bastola & Hu, 2020), In his study, he found that the industrial atmosphere in schools unconsciously shaped student discipline. This is supported by Wijaya's findings, which indicate that the time-delivery component of the TEFA project trains students to manage stress and work in teams. Another reference, Opdal (2022), noted that collaboration among students in completing production orders enhances their interpersonal communication skills, which are essential in the workplace.

In the context of the Curriculum *Merdeka Belajar*, TEFA provides schools with flexibility to develop real projects. The *Projek Penguatan Profil Pelajar Pancasila* can be integrated into TEFA's activities. For example, orders for spare parts from partner industries can be utilized as joint projects that involve mathematics (material calculation), language (business communication), and vocational subjects. This integration, according to Islam (2022), makes learning more meaningful by helping students understand that what they know has direct economic value.

However, criticism of TEFA also emerged. Some education observers, as quoted in the Proctor (paper, are worried about the exploitation of students as cheap labor. Therefore, the boundary between learning and production must be clear. The main goal of TEFA is education (education first, business second). Yuliana's research emphasizes the importance of teachers' dual role as both instructors and supervisors, and the need to maintain this balance. Teachers must ensure that all production order students complete contributes to the achievement of the set basic competencies or learning outcomes.

Recognizing the complexity and potential of this learning model, as well as the urgent need for Surakarta Citizen Vocational Schools to enhance their graduates' employment prospects, this research is highly relevant. This study will test the hypothesis that the average learning outcomes for vocational competencies among students who use the teaching factory model differ significantly from those of students who use the conventional model. The use of ANOVA analysis techniques was chosen for its ability to compare variances between groups with high precision, providing a strong scientific basis for policy-making in schools to continue or modify ongoing theme programs.

Furthermore, international literature also supports the concept of Work-Based Learning, which is the parent of TEFA. A comparative study by Jusslin (2022) compared the Dual System in Germany with the TEFA in Indonesia, concluding that, despite different cultural contexts, the basic principle of "learning while working" remains the most effective approach to vocational education. In Indonesia, this adaptation requires adjustments to infrastructure and mindset. Setyad (2021) highlighted that the readiness of workshop infrastructure in private vocational schools is often an obstacle, but innovative management can overcome these limitations

The synthesis of more than 30 articles reviewed (as presented in the literature) boils down to one tentative conclusion: learning innovation is necessary. The one-way lecture-and-demonstration method is obsolete. Generation Z students need real challenges. They need to see their work in use or being sold. According to the constructivist learning theory, as reviewed by Siregar, intrinsic motivation is a key factor in the success of vocational learning. Thus, this research not only fulfills academic tasks but also seeks to make a real contribution to the development of technical education pedagogy in Indonesia, especially in Surakarta.

Through this comprehensive introduction, the basis for TEFA thinking is not just a momentary trend but a fundamental need for vocational school revitalization, requiring strict control variables and valid assessment instruments. This research is expected to provide irrefutable empirical evidence regarding the superiority of the Teaching Factory model in producing reliable, professional, and job-ready machining technicians.

METHODS

This study uses a quantitative, quasi-experimental research design (pseudo experiment). The research design used was a Nonequivalent Control Group Design. In this design, the experimental and control groups were not randomly selected; instead, they were drawn from an intact group. However, both groups received pretests and posttests to determine the initial and final state of students' competencies. This research is conducted at Vocational High School Warga Surakarta, a vocational education institution equipped with industry-standard machining workshop facilities. The study was conducted during the odd semester of the 2025/2026 school year.

The population and sample in this study comprise all grade XI students majoring in Machining Engineering at Vocational High School Warga Surakarta, which consists of four classes. Sampling was conducted using a cluster random sampling technique. Two classes were selected as samples: class XI TP-A, an experimental group that applied the Teaching Factory learning model, with a total of 32 students; and class XI TP-B, a control group that used the conventional learning model (demonstrations and ordinary guided exercises), with a total of 32 students. The total number of research subjects was 64 students.

Research Variables

1. Independent Variables: The learning model in the experimental group is the Teaching Factory Model (X_1), and the control group is the conventional model (X_2).
2. Dependent Variables: Learning outcomes of vocational competencies in machining engineering (Y), which include cognitive (knowledge) and psychomotor aspects (practical skills of turning/phrasing).

Teaching factory learning procedure in experimental class, learning steps follow the 6-step teaching factory syntax (TF-6M):

1. Receiving Orders: Students receive product specifications from teachers/instructors (in an industrial order simulation).
2. Analyzing Orders: Students analyze working drawings and determine the required tools.
3. Declaring Readiness: Students prepare a work plan (work preparation).
4. Work on Orders: Production process with strict quality control standards.
5. Evaluating Products: Product quality assessment by the student quality control team and teachers.
6. Submission of Order: The final product is assessed for eligibility for "sale" or submission.

Meanwhile, in the control class, learning takes place as the teacher explains the theory, demonstrates exercises, and students imitate them without any simulation or pressure to meet strict industry quality standards (only academic grade-oriented).

The data collection technique involves collecting data using two main instruments.

1. Writing Test: reasoned multiple-choice questions to measure understanding of machining theory, cutting parameters, and K_3 .
2. Performance Test Observation Sheet: A practice assessment rubric that refers to the Indonesian National Work Competency Standards.

The aspects assessed include work preparation, machining process, product dimensions (tolerance), processing time, and work safety. The instrument was validated using content validity (expert judgment) and reliability, as assessed by Cronbach's alpha.

Data analysis technique (ANOVA) to test research hypotheses, the data analysis technique used is one-way Analysis of Variance (ANOVA). The reason for using ANOVA is that this study

aims to compare the average variances of learning outcomes between the treatment and control groups to assess the significance of the difference. Before the ANOVA test, a prerequisite analysis test is carried out, which includes:

1. Normality Test: Using the Kolmogorov-Smirnov or Shapiro-Wilk Test to ensure that the learning outcome data is typically distributed.
2. Homogeneity Test: Using Levene's Test to ensure the variance of data between the experimental and control groups is homogeneous.

The proposed statistical hypotheses are:

H_0 : There was no significant difference in learning outcomes between students taught with the Teaching Factory model and the conventional model ($\mu_1 = \mu_2$).

H_1 : There is a significant difference in learning outcomes between students taught using the Teaching Factory model and the conventional model.

The test criteria are: significance value (Sig.) < 0.05 or $F_{\text{calculated}} > F_{\text{table}}$; then H_0 is rejected, and H_1 is accepted. Statistical calculations are performed using SPSS software version 26.0 to ensure the accuracy of the results.

The research followed a systematic flow consisting of observation, instrument preparation, pretest, intervention, posttest, data analysis, and conclusion. This structured process ensures the reliability and replicability of the study.

This research was conducted through systematic stages, including observation, instrument development, pretest administration, intervention administration, posttest administration, data analysis, and conclusion drawing. This structured series of processes aims to ensure reliability and enable the research to be replicated.



Figure 1. Research Flow of the Study

RESULTS AND DISCUSSION

Results

The results of the research, based on field data from SMK Warga Surakarta, were a recapitulation of the final scores for students' vocational competencies (a combination of cognitive and psychomotor scores). The following is a description of the data from the research results.

1. Descriptive Data

- a. Experimental Group (Teaching Factory): The mean score obtained was 84.50 with a standard deviation of 4.25. The highest score achieved by students was 92, and the lowest was 76.
- b. Control Group (Conventional): The mean score obtained was 76.20 with a standard deviation of 6.10. The highest score is 80, and the lowest is 65.

Visually, the mean difference of 8.30 points indicates that the TEFA group performs better. The smaller standard deviation in the experimental group also suggested that students' abilities were more evenly distributed than in the control class.

2. Analysis Prerequisites Test

- a. Normality Test: The Shapiro-Wilk test results showed Sig. Value for the experimental class of 0.210 and a control class of 0.185. Because both values are >0.05, the data is declared to be normally distributed

- b. Homogeneity Test: The Levene test results showed Sig. A value of 0.342 (>0.05) indicates that the variances of the two groups are homogeneous. The conditions for performing ANOVA are met.

3. Hypothesis Test (One-Way ANOVA) The results of ANOVA calculations are presented in the following summary table of simulations.

Table 1. The results of the Shapiro-Wilk test

Source of Variation	Sum of Squares	df	Mean Square	F	Sig
Intergroup	1240.320	1	1240.320	24.56	0.000
In a Group	3125.450	62	50.410		
Total	4365.770	63			

Based on the table above, the value of F_{count} is 24.56, with degrees of freedom (df) of 1 and 62 at the 5% significance level. The value of the F_{table} is approximately 1 and 62 degrees of freedom (df) at a significance level of 5%. The value of F_{table} is approximately 3.99. because F_{count} (24.56) $> F_{\text{table}}$ (3.99) and the significance value of $0.00 < 0.05$, the test decision is to reject H_0 and accept H_1 . This means that the application of the Teaching Factory learning model has a significant influence on students' learning outcomes in machining engineering competencies at Vocational High School Warga Surakarta.

Discussion

The discussion of this study's results confirms that the Teaching Factory approach at Vocational High School Warga Surakarta has a substantial positive impact compared to conventional methods. An in-depth analysis of data and learning processes reveals some of the key factors to this success.

1. The industrial atmosphere fosters discipline. In the TEFA model, students not only learn to operate machines but also acquire a culture. Strict Quality Control standards encourage students to be more meticulous in their work. In conventional learning, the tolerance of the workpiece size is often understood. In TEFA, workpieces that are out of tolerance are considered rejected or failed. This forces students to improve their precision and prudence. This finding aligns with Hartono's research, which suggests that factory learning automatically enhances students' sense of quality.
2. Increased motivation through real product points motivates students in the experimental class to show higher enthusiasm because they know the objects they make have a practical use or selling value, in contrast to the control class, which often only works on practice job sheets that will eventually be discarded in the scrap warehouse. Emotional engagement with this product increases student knowledge retention. As explained in the constructivist theory cited by Yadav, (2022) learning becomes meaningful when students construct knowledge through authentic, relevant experiences.
3. The collaboration and management of TEFA learning time at Vocational High School Warga Surakarta requires students to work within the production flow. Some students are responsible for material preparation, lathe operation, milling machine operation, and finishing. This role rotation trains managerial skills and teamwork. Students learn that delays at one post will hinder another. This aspect is less developed in conventional models, which tend to be individualistic. This supports the study by Ahmadin, (2022), which suggests that TEFA is effective in developing collaborative soft skills.

Statistically, ANOVA confirms this distinction. The minor variance in the experimental class indicated that TEFA enhanced the ability of slow learners through the peer tutoring mechanism

within the production team. In contrast, in the control class, the gap between the smart and less intelligent students was wider (higher standard deviation).

However, this study also noted several challenges: implementing TEFA requires additional teacher readiness in terms of supervision and management of raw materials. At Vocational High School Warga Surakarta, this is achieved through the involvement of guest instructors from the industry, who provide insight into the latest industry standards and best practices. This synergy has proven to be effective in maintaining the quality of learning. These findings suggest that the machining engineering curriculum should transition immediately from a pseudo-exercise-based approach to a real-world production-based approach. Schools need to invest not only in tools but in production management systems that allow TEFA learning to run sustainably.

CONCLUSION

Based on the results of data analysis and hypothesis testing using TEFA, it can be concluded that the application of Teaching Factory-based learning significantly improves the competence in machining engineering skills of grade XI students at Vocational High School Warga Surakarta. Students who participated in learning using the TEFA model demonstrated higher learning outcomes, both in technical skills (precision and speed of work) and non-technical aspects (discipline, responsibility, and quality), compared to those in conventional learning. The TEFA model has proven effective in bridging the gap between school and industry competencies by introducing a realistic work atmosphere into the school's practice space.

Based on the above conclusion, Vocational High School Warga Surakarta is expected to expand the scope of TEFA not only in specific production subjects but also to integrate it across curricula and strengthen partnerships with industry to obtain sustainable real orders. Meanwhile, teachers are expected to continue improving production managers' competence and shift the paradigm from merely being teachers to productive supervisors who guide students in achieving industry standards. It is necessary to conduct further research to measure the effectiveness of TEFA on the absorption of graduates (employment) after they graduate, or to examine the aspects of production cost efficiency in the implementation of TEFA.

CONFLICT OF INTEREST

There are no conflicts of interest to report for any author.

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Mapping Computational Thinking in the Era of Digital Transformation for Education toward SDG 4: A Bibliometric Analysis

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ABSTRACT

Computational Thinking (CT) has emerged as an important competency in education in response to ongoing digital transformation and the increasing emphasis on Sustainable Development Goal 4 (SDG 4). This study employs bibliometric analysis to examine CT-related publications from 2015 to 2025. Network, cluster, and overlay visualization techniques were used to identify key research trends, thematic developments, and collaboration patterns in the field. The results indicate a continuous growth in CT research and a shift from viewing CT primarily as a programming skill toward a broader cognitive and pedagogical construct involving problem solving, abstraction, and adaptive reasoning. CT is predominantly associated with workforce preparation, teacher capacity-building, and instructional innovation across educational contexts. While research has expanded into areas such as early childhood education and digital learning environments, topics related to equity, sustainability, and global citizenship remain relatively underexplored. Overall, this study highlights the evolving conceptualization of CT in education and underscores the need for more inclusive and sustainability-oriented research in future studies.

Keywords: *Computational Thinking, Digital Transformation, Bibliometric Analysis, SDG 4, Education*



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INTRODUCTION

Digital transformation has significantly changed educational, social, and professional practices in contemporary society. The rapid growth of technologies such as artificial intelligence, big data, and the Internet of Things has increased the demand for individuals who possess digital literacy and strong problem-solving skills. In addition, emerging educational technologies such as the metaverse are reshaping learning environments by enabling more immersive, interactive, and virtual-based educational experiences (Alhakimi, 2023). As a result, education systems are expected to prepare students with skills relevant to the modern workforce and the Sustainable Development Goals (SDGs). Among these competencies, Computational Thinking (CT) has emerged as an important problem-solving framework, encompassing decomposition, abstraction, pattern recognition, algorithmic design, and evaluation (Shute et al., 2017; Voogt et al., 2015). Consequently, CT has gained increasing attention in discussions of digital transformation and education.

Although CT originated in computer science, it is now applied in various disciplines, including mathematics, science, and engineering education. Several studies have shown that CT can be integrated into mathematics, science, engineering, social studies, and interdisciplinary learning environments to enhance analytical reasoning and creativity (Li et al., 2020; Weintrop et al., 2016). Within mathematics and science education, CT supports modelling, simulation, data interpretation, and logical reasoning. In broader educational contexts, CT also supports collaboration, creativity, and adaptive thinking skills. These characteristics make CT relevant to the achievement of SDG 4, which aims to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.

Recent studies have reported several educational benefits associated with CT. For example, a systematic review by Tang et al. (2020) found that CT interventions positively influence students' problem-solving skills, programming comprehension, and cognitive performance. Lee et al. (2022) similarly reported that CT-based learning raises engagement, creativity, and academic achievement in K–12 contexts. In STEM education, CT is associated with greater innovation capacity and improved practical problem-solving (Tariq et al., 2025). Supporting this, computational thinking is also closely linked to metacognitive processes that enhance learners' self-regulation and cognitive control (Buwono et al., 2025). These findings suggest that CT can contribute to improving educational quality and helping students adapt to technology-driven environments.

Despite these benefits, CT implementation still varies considerably across countries and educational systems. While many developed countries have integrated CT into school curricula, teacher training, and national digital strategies, developing countries continue to face challenges in infrastructure, curriculum development, teacher expertise, and policy integration. Furthermore, CT is frequently interpreted narrowly as coding or programming, thereby limiting its broader pedagogical potential as a cross-disciplinary cognitive approach (Grover & Pea, 2018). Differences in how CT is defined, assessed, and taught also create challenges for curriculum integration. These disparities may limit the role of CT in supporting equitable digital transformation.

The growing number of CT studies has increased the need for bibliometric analyses that map research trends and developments in the field. Bibliometric studies have begun to examine publication trends, influential authors, collaboration networks, and emerging research themes. Rafiq et al. (2023) observed a substantial increase in CT research output from 1987 to 2023, particularly after 2015, with major contributions from technologically advanced countries. Recent research has studied domain-specific topics such as science learning for SDGs (Erwinsyah et al., 2025), CT and project-based learning for SDG 6 (Samodra et al., 2025), CT in mathematics education (Sumarno et al., 2025), and CT in children's education for sustainable futures (Mee et al., 2025).

However, despite this growing body of literature, three main limitations can still be observed in many studies published between 2020 and 2025. First, the research is often spread across different areas (such as STEM education, programming, and specific SDG topics), rather than providing an integrated perspective. Second, many studies primarily rely on basic bibliometric measures such as publication counts, citation analysis, and author productivity. Third, the relationship between computational thinking, digital transformation, and SDG 4 has not yet been consistently examined within a unified bibliometric framework, as these topics are frequently treated separately at either thematic or descriptive levels.

Accordingly, this study presents a bibliometric analysis of CT research in the context of digital transformation and SDG 4. This study examines publication trends, influential authors, country contributions, and keyword co-occurrence patterns to understand how CT research has developed globally. It applies a combined approach that includes performance analysis, science mapping, and thematic visualization within a single framework. This approach provides a more

complete overview of the main structure and themes in CT research by positioning computational thinking within both digital transformation and SDG 4 discussions, rather than treating them separately. In this way, the study offers a more connected view of the field and helps explain the development of CT research in education over time. Ultimately, this study aims to show how CT contributes to improving educational quality, equity, and sustainability in the era of digital transformation.

METHODS

This study employed a bibliometric approach to examine research on computational thinking in the context of digital transformation and its relation to SDG 4 on quality education. Bibliometric analysis is commonly used to identify publication trends, research patterns, and the development of scientific fields (Donthu et al., 2021). Data were collected using Publish or Perish (PoP) software with Google Scholar as the primary database. Google Scholar was selected because it provides broad coverage of international publications, including journal articles, conference papers, and early-access studies (Halevi et al., 2017). The search focused on publications published between 2015 and 2025 to capture recent developments in digital transformation and education.

The research procedure was conducted chronologically in four stages: data searching, data screening, data extraction, and bibliometric analysis. In the first stage, combinations of keywords related to computational thinking (e.g., “computational thinking”, “algorithmic thinking”), digital transformation (e.g., “digital learning”, “digital skills”, “educational technology”), and SDG 4 (e.g., “quality education”, “sustainable development goals”) were used. The keywords were combined using the Boolean operators “AND” and “OR” to ensure comprehensive retrieval of relevant publications. To obtain a broad yet manageable dataset, the 200 most relevant publications from each keyword group were selected, resulting in an initial dataset of 600 documents. Only publications written in English were included in the analysis.

In the second stage, the collected documents underwent several filtering processes to improve dataset relevance and consistency. After duplicate removal, 573 documents remained. The titles and abstracts were manually screened to identify studies specifically related to computational thinking and SDG 4, resulting in 152 relevant documents. In the final screening stage, books and reports were excluded to maintain consistency in publication type and focus only on peer-reviewed journal articles and conference papers. The final dataset consisted of 148 publications.

In the third stage, all selected documents were exported in RIS format for data extraction using VOSviewer software. Bibliographic information such as titles, authors, keywords, publication years, and citation data was organized and prepared for visualization analysis.

In the fourth stage, bibliometric analysis was conducted using VOSviewer. The analysis consisted of three visualization methods. First, network visualization was applied to identify relationships among keywords, authors, and publications. Second, overlay visualization was used to examine the evolution of research topics over time based on the average publication year. Third, density visualization was conducted to identify the most frequently discussed topics within the dataset (Cobo et al., 2011; van Eck & Waltman, 2010).

RESULTS AND DISCUSSION

Results

1. *Most Influential Publications in Computational Thinking Research*

Bibliometric analysis identified the 10 most influential publications on CT during the period of digital transformation (see **Table 1**). Korkmaz et al. (2017) received the highest number of citations (928), mainly due to the development of a widely used instrument for

measuring CT skills. Nouri et al. (2020) focused on integrating programming and digital competencies in K–9 education, while Oliveira and De Souza (2022) recorded the highest average citation rate per year (110.25 citations), reflecting growing interest in Education 4.0. Other highly cited studies examined CT integration in STEM education (Wang et al., 2022), mathematics learning (Sung et al., 2017), game-based learning (Hooshyar et al., 2021), Scratch-supported distance learning (Marcelino et al., 2018), CT assessment approaches (Cutumisu et al., 2019), and robot programming in early childhood education (Yang et al., 2022).

Table 1. List of Influential Articles

Cites	Authors	Title	Cites Per Year	Country
928	Korkmaz et al. (2017)	A validity and reliability study of the computational thinking scales (CTS)	103.11	Turkey
513	Nouri et al. (2020)	Development of computational thinking, digital competence and 21st century skills when learning programming in K-9	85.50	Sweden
441	Oliveira and De Souza (2022)	Digital transformation towards education 4.0	110.25	Brazil
291	Wang et al. (2022)	Integrating computational thinking in STEM education: A literature review	72.75	USA
260	Sung et al. (2017)	Introducing computational thinking to young learners: Practicing computational perspectives through embodiment in mathematics education	28.89	USA
260	Iversen et al. (2018)	From computational thinking to computational empowerment: a 21st century PD agenda	32.50	Denmark
205	Marcelino et al. (2018)	Learning computational thinking and scratch at distance	25.63	Portugal
202	Hooshyar et al. (2021)	From gaming to computational thinking: An adaptive educational computer game-based learning approach	40.40	Estonia
192	Cutumisu et al. (2019)	A scoping review of empirical research on recent computational thinking assessments	27.43	Canada
159	Yang et al. (2022)	Robot programming versus block play in early childhood education: Effects on computational thinking, sequencing ability, and self-regulation	39.75	China

Overall, these influential studies demonstrate that CT has expanded across multiple educational contexts and technological approaches. Most highly cited publications were produced in Europe and North America, suggesting strong research activity in digital education within these regions.

2. Thematic Clustering of Computational Thinking Research

Co-occurrence analysis of terms in titles and abstracts revealed the thematic structure of CT literature within the context of digital transformation and SDG 4. The resulting clusters

Teacher capacity-building (Target 4.c) remains essential for CT implementation. In line with Butler and Leahy (2021) and Liu et al. (2024), pedagogical competence and institutional support are more influential than technology access alone. However, unlike Ung et al. (2022), which emphasizes individual teacher capacity, this study highlights a shift toward broader digital learning systems within schools and institutions, suggesting a more sustainable implementation model. Nevertheless, most highly cited studies originate from Europe and North America, while evidence from developing countries remains relatively limited.

In formal education contexts (Targets 4.1 and 4.3), CT is increasingly applied through project-based learning, inquiry-based learning (Ogegbo & Ramnarain, 2022), Scratch (Marcelino et al., 2018), and robotics (Kerimbayev et al., 2023; Yang et al., 2022). Compared with earlier studies (Hooshyar et al., 2021; Sung et al., 2017), which focus mainly on engagement and cognition, this study shows that CT has expanded beyond STEM into disciplines such as business, health, and social sciences (Lee & Malyn-Smith, 2020), confirming its role as a skill that can be used across many subjects, not only STEM areas.

Moderate contributions are found in Targets 4.6, 4.2, and 4.a, particularly in literacy and numeracy development, early childhood education, and inclusive and effective learning environments. CT is strongly associated with logical thinking, sequencing, and data literacy, consistent with Korkmaz et al. (2017) and Bilbao et al. (2025), which provide structured ways to measure CT skills in different educational settings. In early childhood education, block-based programming and robotics improve early CT skills (Yang et al., 2022; Zeng et al., 2023). These findings indicate that CT develops in a stepwise manner across educational levels, depending on teaching methods and available facilities.

However, Targets 4.5, 4.7, and 4.b remain underexplored, particularly in relation to equitable and inclusive access to education, education for sustainable development and global citizenship, and scholarship opportunities for learners from developing countries. This aligns with Tikva and Tambouris (2021), who also report dominance of technical and employability perspectives. Nevertheless, emerging studies by Iversen et al. (2018) and Tongal et al. (2024) show a gradual shift toward computational empowerment, creativity, and sustainability-oriented learning, although these perspectives remain emerging rather than dominant.

Overall, CT research is associated with multiple SDG 4 targets, with the most frequent associations observed in skills development for employment and entrepreneurship (Target 4.4), teacher capacity-building (Target 4.c), and support for quality education at primary, secondary, and tertiary levels (Targets 4.1 and 4.3). Contributions to Targets 4.6, 4.2, and 4.a are also present, while Targets 4.5, 4.7, and 4.b are less frequently represented in the literature. These patterns indicate an uneven distribution of research attention across SDG 4 targets in CT studies within the context of digital transformation, with a stronger emphasis on employability-oriented skills and teacher development compared to educational inclusion, education for sustainable development, global citizenship, and human rights. By mapping CT research across SDG 4 targets, this study provides a structured overview of the distribution of scholarly attention across dimensions of educational development and identifies areas that may benefit from further research.

CONCLUSION

This study finds that CT has become a well-established research domain contributing to SDG 4 within the context of digital transformation. The results reveal a distinct shift in CT conceptualization from a focus on programming skills to broader competencies, including problem-solving, abstraction, pattern recognition, and adaptability. CT's strongest contributions are observed in Targets 4.4, 4.c, 4.1, and 4.3, particularly in skills development for employment and entrepreneurship, teacher capacity-building, and support for quality primary, secondary, and tertiary education. Moderate contributions are evident in Targets 4.6, 4.2, and 4.a, whereas

Targets 4.5, 4.7, and 4.b remain insufficiently addressed, particularly in relation to equitable and inclusive access to education, education for sustainable development and global citizenship, and scholarship opportunities for learners from developing countries. Overall, CT serves as both a technical and educational literacy, bridging digital transformation with broader educational objectives. The study highlights the uneven distribution of research attention across SDG 4 dimensions and calls for more integrated approaches that strengthen inclusion, sustainability, and educational equity in future CT research.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Qualitative Analysis of Student Discipline Among Children of Migrant Parents and Its Implications for Instructional Innovation at SD Negeri Adirejakulon

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ABSTRACT

The discipline of students with the background of migrating parents is the subject of this research. This study aims to analyze the discipline of students with the background of migrating parents at SD Negeri Adirejakulon, Adipala District, Cilacap Regency. The descriptive qualitative approach with the case study method is the approach and method used in this study. The research subjects in this study are students, parents, and teachers. Data collection techniques through observation, interviews, and documentation. The results of the study show that the attitude of students who have high discipline shows responsibility in carrying out every rule and task given which consists of time discipline, such as being on time in learning, doing assignments according to responsibility, compliance with school rules and discipline of actions, such as obedience to the rules of the game and school activities, neatness and conformity with dress standards, involvement in maintaining order, awareness and self-control. Migrating parents do not carry out their role optimally, especially in terms of providing guidance and assistance. Parental participation is needed to create a conducive learning atmosphere and form positive habits for children.

Keywords: Instructional Innovation, Migrant Parents, Qualitative Analysis, Students Discipline.



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INTRODUCTION

Education is the main foundation in building an advanced and civilized civilization. Surah At Tahrim verse 6 touches on the importance of Islamic education from an early age. A good pattern of education will provide an understanding of religion that is pleasing to Allah ﷻ. This understanding is what gives birth to the bond to maintain each other's safety in this world and the hereafter.

Rasulullah ﷺ said: "There is no better gift a father gives to his son than good manners." (H.R Tirmidzi Number 1952). This hadith narrates the obligation to educate children well. Parents are obliged to educate their children with Islamic values and good morals. Article 12 of Law Number 39 of 1999 concerning Human Rights states that everyone has the right to protection for their personal development, educating themselves and improving their quality of life in order to become a human being who is faithful, devout, responsible, noble, happy, and prosperous in accordance with human rights.

The family is the first environment that influences various aspects of child development (Y. Suyitno, 2021). The family is a good place for children's socialization because most of the time is spent by children in the family (Andriani, A., Muntohar, & Fathoni, 2023). The role of parents as mentors and role models for children is very important in shaping children's personality, attitudes, and moral values from an early age (Pahlevi et al., 2022; Ward et al., 2024; Bălătescu et al., 2023).

The problem that exists at SD Negeri Adirejakulon Adipala, Cilacap is the lack of attention from migrating parents in guiding the discipline of students. The researcher took a formulation of the problem regarding how the discipline of students with the background of their parents migrated. The purpose of this study is to analyze the discipline of students with the background of migrating parents. This research is useful for new strategies in improving student discipline and can help students understand the importance of discipline in daily life.

Human behavior is influenced by efforts to meet basic needs arranged hierarchically, ranging from physiological needs to self-actualization (Maslow, 1954). The stages of Maslow's needs include: physiological, security, affection and belonging, self-esteem, and self-actualization. Children who are left behind by migrating parents often experience a lack of affection and a sense of belonging.

Parental migration has become a global social phenomenon that affects children's educational experiences and psychosocial development. Studies have reported that children left behind by migrant parents often experience reduced parental supervision, emotional distance, and challenges in behavioral adjustment, which may affect their academic engagement and disciplinary behavior (Khalid et al., 2023; Liu et al., 2024; Qiu et al., 2024).

The character possessed by a person is basically formed through a fairly long learning process. The parties that play an important role in shaping a person's character are family, teachers, and peers (Andriani & Wakhudin, 2020). The character of student discipline can be improved through the active role of teachers through five dimensions, including instructors, educators, supervisors, trainers, evaluators). The consistent and continuous use of these methods helps to internalize discipline as a character (Arto & Wakhudin, 2021).

Discipline is individual behavior that is able to comply with values and norms that people or groups believe in (Mukhasin & Andriani, 2021). The types of disciplines seen from the approach are as follows: 1) Discipline that emphasizes obedience is focusing on obedience to the rules and instructions of teachers or authorities. 2) Discipline that emphasizes value understanding aims to make students internalize values so that they are obedient because they understand and believe in them (Lickona, 2013).

Discipline indicators can be detailed concretely such as, time discipline, including: 1) Punctuality in attendance, 2) Doing tasks according to responsibilities and provisions, 3) Compliance with class and school rules. Discipline includes: 1) Obedience to the rules of certain games and activities, 2) Neatness and suitability in dressing, 3) Involvement in maintaining order, 4) Awareness and self-control (Agustin Sukses Dakhi, 2020).

Student discipline is an essential component of successful learning because it promotes responsibility, self-control, and compliance with educational expectations. Contemporary research emphasizes that discipline should not merely focus on obedience but should foster self-regulation and intrinsic responsibility through supportive learning environments (Bear, 2011; Gregory et al., 2021; Simonsen et al., 2022).

Children's development is greatly influenced by the process of parental treatment or guidance for children in getting to know various aspects of social life, or norms of social life and encouraging and setting an example for their children on how to apply these norms in daily life (Andriani, A., Muntohar, & Fathoni, 2023). The role of parents in education includes: 1) Parents as educators, 2) Parents as encouragers, 3) Parents as facilitators and 4) Parents as supervisors (Ahmid, 2015).

The impact of children who are left behind by their parents is that children have psychosocial problems resulting from the lack of attachment between children and parents. The absence of parents due to migration will result in a less fulfilled approach relationship and attachment relationship between children and parents (Rahman et al., 2024).

The process of migrating is imbued with a futuristic spirit to improve life, reflecting that migrating is not only about changing places, but also maintaining togetherness and communal identity in conditions. Parents choose to migrate because of economic limitations in their home areas, such as lack of jobs, low income, and difficulty meeting family needs. They choose to work outside the region or abroad, in the hope of sending their children to a higher level because the wages they receive are much higher (Zahroh, 2023).

Previous research has shown that the family is the main environment in the process of socialization and character formation of children (Andriani & Wakhudin, 2020). The absence of migrating parents has an impact on the reduction of emotional closeness between parents and children (Rahman et al., 2024). Other research also explains that migrating is generally done because of economic encouragement to improve family welfare (Zahroh, 2023). The study has not studied much about how children's discipline and learning habits are when parents travel.

The novelty of this research lies in the formation of children's discipline and learning habits when parents migrate both at home and at school. The role of teachers and parents/guardians is a motivator and facilitator in improving student discipline. The study describes how the patterns of guidance, direction, and control provided by children's companions at home and at school affect children's learning motivation, responsibility, and disciplined behavior both at home and at school. Recent educational studies suggest that disciplined behavior is closely associated with self-regulated learning. Students who effectively manage their learning activities tend to demonstrate stronger time-management skills, task completion rates, and behavioral control during classroom activities (de Boer et al., 2023; Cheng et al., 2024; Zimmerman, 2020).

Previous studies have extensively examined parental involvement, character education, and student discipline in elementary schools. However, limited research has specifically investigated how student discipline is developed among children whose parents migrate for employment, particularly within rural Indonesian elementary school contexts. Existing studies primarily focus on psychosocial impacts, parenting styles, and academic achievement, while the instructional strategies employed by teachers to compensate for reduced parental presence remain underexplored (Ward et al., 2024; Zhang et al., 2024; Alfiasari et al., 2025).

The absence of migrant parents may weaken direct supervision; however, schools can compensate through instructional innovation. Structured routines, positive behavioral interventions, collaborative teacher-guardian communication, and social-emotional learning practices have been shown to strengthen student discipline and self-regulation (CASEL, 2023; OECD, 2023; UNESCO, 2024)

Furthermore, little is known about how collaboration between teachers, guardians, and migrant parents contributes to discipline formation in daily learning activities. This gap is particularly evident in schools where a substantial number of students are raised by extended family members due to parental migration (El Alaoui & Ahbala, 2024; Li, 2023).

Therefore, this study offers novelty by examining student discipline through the lens of instructional innovation and collaborative discipline-building practices involving teachers, guardians, and migrant parents at SD Negeri Adirejakulon, Cilacap, Indonesia.

METHODS

This study uses a qualitative research approach with a case study method. Qualitative research is a method to explore and understand the meaning that a number of individuals or a group of people consider to come from social or humanitarian problems (Creswell, 2023). Case

studies are research designs that are widely used in various fields, especially in evaluation (Creswell, 2023).

The data source in this study uses purposive sampling techniques and snowball sampling techniques. Purposive sampling can be explained by a sampling technique with certain considerations based on meeting information needs. Snowball sampling is a sampling technique that starts small and then develops into more in line with the development of information and data fulfillment. The subject of the study is students at SDN Adirejakulon, Adipala District, Cilacap Regency who have different disciplines reviewed from the background of their parents abroad.

The data collection techniques used in this study are observation, interviews, and documentation.

1. Observation

The observation carried out in this study aims to obtain data related to the discipline of students at SD Negeri Adirejakulon, Adipala District, Cilacap Regency with the background of parents abroad, so that a thorough observation is needed regarding various aspects to be studied.

2. Interview

The types of interviews used in data collection are: (1) structured interviews, (2) semi structured interviews, and (3) unstructured interviews (Amir Hamzah, 2020: 67). Interviews in this study were conducted with students, parents of students and teachers at SD Negeri Adirejakulon, Adipala District, Cilacap Regency to obtain information about student discipline reviewed from the background of parents abroad.

3. Documentation

Documentation was conducted to obtain supporting data relevant to the research objectives, including school records, student attendance reports, discipline records, photographs of school activities, and other documents related to students' disciplinary behavior. These documents were used to complement and verify data obtained through observations and interviews.

The data were analyzed using the five-phase qualitative data analysis framework proposed by Bingham (2023). This framework emphasizes a systematic and iterative process consisting of data organization, coding, memoing, pattern identification, and interpretation. The approach enables researchers to produce rigorous and trustworthy findings while maintaining transparency throughout the analytical process.

1) Data Organization

The first phase involved organizing data obtained from observations, interviews, and documentation. All field notes, interview transcripts, and supporting documents were compiled, classified, and stored systematically. Organizing the data allowed the researcher to become familiar with the information and prepare it for further analysis (Bingham, 2023).

2) Coding

In the second phase, the researcher conducted coding by assigning labels to meaningful segments of data. Codes were developed from participants' statements, observed behaviors, and documentary evidence related to student discipline, parental involvement, responsibility, punctuality, and instructional practices. Coding helped identify significant concepts emerging from the data (Bingham, 2023).

3) Memoing and Categorization

After coding, analytical memos were written to record reflections, interpretations, and emerging ideas. Similar codes were grouped into broader categories representing recurring themes. For example, codes related to punctuality, task completion, and rule compliance were

categorized under “disciplinary behavior,” while codes related to teacher guidance and parental support were categorized under “discipline support mechanisms” (Bingham, 2023).

4) Pattern Identification and Theme Development

The researcher then examined relationships among categories to identify patterns and themes. This stage focused on understanding how teacher practices, parental migration, and guardian involvement influenced students’ disciplinary behaviors. Themes were continuously refined through comparison across multiple data sources to ensure consistency and credibility (Bingham, 2023).

5) Interpretation and Conclusion Drawing

The final phase involved interpreting the identified themes and connecting them with relevant theoretical perspectives and previous studies. Conclusions were drawn based on the overall meaning of the data and verified through continuous comparison among observation, interview, and documentation findings. This process ensured that the conclusions accurately reflected participants’ experiences and the research context (Bingham, 2023).

The data validity test is the last stage in qualitative research, but it does not mean that researchers do not return to the field (Hamzah, 2020). To ensure the trustworthiness of qualitative findings, researchers should address four key criteria: credibility, transferability, dependability, and confirmability. These criteria are widely recognized as essential indicators of rigor in qualitative research. In this study, data trustworthiness was established primarily through credibility procedures using methodological triangulation, which involved comparing data obtained from observations, interviews, and documentation to enhance the accuracy and consistency of the findings (Korstjens & Moser, 2020; Bingham, 2023). The validity of the data in this study was tested by a credibility test using the triangulation method.

1. Triangulation of sources

Source triangulation is used to test credibility by checking the degree of trust of information obtained from participants.

2. Triangulation Technique

Triangulation techniques are used to check data on the same source with different techniques. The techniques used are interview, observation and documentation.

RESULTS AND DISCUSSION

Results

Discipline of Students with the Background of Migrating Parents in the Cluster of dr. Wahidin Sudirohusodo Adipala, Cilacap. The results of observations carried out at SD Negeri Adirejakulon showed that most of the students came and went to school on time. Students also do assignments according to their responsibilities and provisions even though there are still some children who violate them. Involvement in maintaining class and school order can be seen as they keep each other's classrooms orderly.

Teachers provide positive habits at school to form disciplined behavior. "I instill a habit such as before entering class, children always line up in front of the class, some prepare in turn every day, because for me the marching line can improve children's discipline," said Mrs. Diana.

Student discipline is one of the important factors in the success of the learning process at school. Students who are able to arrive on time every day show responsibility for their obligations as students and the ability to manage time well. "I was never late to school, but I was in 3rd grade once. I also never stop by and go straight home," said Eka.

Disciplined behavior must be applied both at home and at school. Parents who migrate cannot fully accompany their children at home." Even though I'm a traveler, I still pay attention to my son, I often call when I'm free. I remind you to learn, don't keep playing, so that you can be a successful child," said Eka's mother when interviewed by phone.

Teachers have a strategic role in replacing the control and coaching functions that are usually carried out by parents, especially through positive habituation that can lead students to behave in discipline. "In learning activities, I instill discipline through habituation such as being on time, bringing study supplies, and completing assignments according to schedule," said Mr. Eri in his interview during the break.

Students do assignments in accordance with applicable responsibilities and regulations. Some students still need reinforcement and guidance to be more consistent in maintaining this attitude of responsibility. "I study at 7 pm, so that I don't miss books so I schedule and prepare school supplies as well. I once forgot to schedule because I didn't study at night due to sleep, finally I forgot not to bring textbooks and didn't do homework," said Earlita.

Parents have an important role in improving student discipline. "I explain to my children that obeying the rules is important to become a successful child. Rules at home and at school must be obeyed. If you don't want to be angry, just follow the rules. Homework must be done, leaving must not be late, don't be rude if the teacher is explaining," said Mr. Earlita when interviewed at his home.

Teachers provide habituation, direction, and examples of discipline in the school environment, while parents provide support and strengthening. Students will more easily form positive habits, when disciplinary rules and values are applied consistently in both environments.

Discussion

Discipline of Students with the Background of Migrating Parents in the Cluster of dr. Wahidin Sudirohusodo Adipala, Cilacap. The family plays the role of the first education that instills the foundations of morals, habits, and good attitudes in life. Teachers in schools strengthen and develop this character through learning activities, examples, and habituation in school life. Andriani & Wakhudin (2020) stated that character formation is the result of collaboration from various parties involved in a person's life.

Arto & Wakhudin (2021) stated that students' disciplinary character can be improved through the active role of teachers through five dimensions, including instructors, educators, supervisors, trainers, evaluators). The consistent and continuous use of these methods helps to internalize discipline as a student's character. Mukhasin & Andriani (2021) states that discipline is an individual behavior that is able to comply with values and norms that people or groups believe.

Students who apply discipline habits are seen to comply and instill discipline values from an early age. Lickona (2013) put forward types, including: discipline that emphasizes compliance (Compliance Discipline), which focuses on obedience to the rules and instructions of teachers or authorities; Value-Based Discipline aims to make students internalize values so that they are obedient because they understand and believe in them.

The results of the study show that students do assignments according to responsibilities and provisions. Dakhi (2020) mentioned several indicators such as time discipline, including: 1) Punctuality in attendance, 2) Doing assignments according to responsibilities and provisions, 3) Compliance with class and school rules. Discipline includes: 1) Obedience to the rules of certain games and activities, 2) Neatness and conformity with dress standards, 3) Involvement in maintaining order, 4) Awareness and self-control.

Parents have an important role in improving student discipline. Andriani et al. (2023) explained that children's development is greatly influenced by the process of parental treatment or guidance for children in getting to know various aspects of social life, or norms of social life and encouraging and setting an example for their children on how to apply these norms in daily life. Ahmid (2015) further states that the role of parents in education includes: 1) Parents as educators, 2) Parents as encouragers, 3) Parents as facilitators and 4) Parents as guides.

Disciplined behavior must be applied both at home and at school. Parents who migrate cannot fully accompany their children at home. Zahroh (2023) stated that the impact of children left behind by their parents is that children have psychosocial problems resulting from the lack of attachment between children and parents.

The findings indicate that teachers implemented several instructional innovations to compensate for the limited parental supervision experienced by children of migrant parents. These innovations included structured classroom routines, daily discipline monitoring, responsibility-based learning tasks, positive reinforcement strategies, and continuous communication with guardians (Fullan, 2021; Darling-Hammond, 2024; UNESCO, 2024).

Such practices align with contemporary instructional innovation frameworks emphasizing student self-regulation, social-emotional learning, and collaborative learning environments. Through consistent habituation and reflective practices, teachers transformed disciplinary expectations into meaningful learning experiences rather than merely enforcing compliance (CASEL, 2023; OECD, 2024; Hattie, 2023).

The findings are consistent with Bronfenbrenner's Ecological Systems Theory, which emphasizes the interaction between family and school environments in shaping children's behavior. In the absence of direct parental supervision, teachers become significant agents within the child's microsystem (Ward et al., 2024; Zhang et al., 2024; El Alaoui & Ahbala, 2024).

The results also support contemporary perspectives on Self-Regulated Learning, suggesting that disciplined behaviors emerge when students develop responsibility, self-monitoring, and time-management skills. Furthermore, the instructional practices observed resemble Positive Behavioral Interventions and Supports (PBIS), which advocate preventive and supportive approaches to behavior management rather than punitive measures (de Boer et al., 2023; Simonsen et al., 2022; Wang & Degol, 2022).

CONCLUSION

This study demonstrates that students with migrant-parent backgrounds at SD Negeri Adirejakulon generally exhibit positive disciplinary behaviors reflected in punctuality, responsibility in completing assignments, compliance with school regulations, and active participation in maintaining classroom order. Although parental migration reduces direct supervision and guidance at home, teachers play a crucial role in fostering discipline through instructional innovations, positive habituation, structured learning routines, and continuous reinforcement. The collaboration among teachers, guardians, and migrant parents contributes significantly to the development of students' self-regulation, responsibility, and learning discipline. These findings suggest that effective instructional innovation can mitigate challenges associated with parental migration and support character development among elementary school students.

CONFLICT OF INTEREST

The author states that there is no conflict of interest in this study. Research is conducted independently without any influence from any party, either in the form of funding, personal relationships, or certain affiliations that may affect the objectivity of research results.

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The Effect of Augmented Reality-Based Learning Media on Higher Order Thinking Skills (HOTS) of Junior High School Students

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ABSTRACT

The low level of Higher Order Thinking Skills (HOTS) among junior high school students in Indonesia, particularly in three-dimensional geometry, requires innovative instructional solutions. This study aims to investigate the effect of Augmented Reality (AR)-based learning media on the HOTS improvement of eighth-grade students in the topic of solid geometry at SMP Negeri 27 Surakarta. A quasi-experimental approach with a pretest-posttest control group design was employed. The sample consisted of 63 students (experimental group: n=31, control group: n=32) selected through purposive sampling. Data collection instruments were HOTS tests based on the revised Bloom's taxonomy (C4–C6), validated by experts. Data were analyzed using the Shapiro-Wilk normality test, Levene's homogeneity test, independent sample t-test, and N-Gain analysis. Results showed that the mean posttest score of the experimental group (75.11) was significantly higher than the control group (51.49). The independent sample t-test yielded a significance value of <0.001 ($t = -11.348$), leading to rejection of H_0 . N-Gain analysis indicated an improvement of 60.31% (fairly effective category) in the experimental group versus 23.33% (ineffective category) in the control group. It is concluded that AR-based learning media significantly improves students' HOTS in solid geometry.

Keywords: *Augmented Reality, Higher Order Thinking Skills, Junior High School Mathematics, Learning Media, Solid Geometry*



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INTRODUCTION

Twenty-first-century education demands higher-order thinking skills as the primary competency that students must possess. Higher Order Thinking Skills (HOTS), encompassing the abilities to analyze (C4), evaluate (C5), and create (C6) based on the revised Bloom's taxonomy by Anderson & Krathwohl (2001), are required by the Indonesian national curriculum, in line with Law Number 20 of 2003 on the National Education System, which emphasizes developing students' creative and independent potential. However, the demands of the 21st century are not limited to critical-mathematical thinking skills, but also include readiness to adapt to the massive development of digital multimedia in various educational institutions worldwide (Setyaningsih, 2023).

Today's digital multimedia has transformed from mere text and sound to a combination of graphics, animation, and interactive video that has a tremendous impact on the way students

construct knowledge (Setyaningsih, 2023). Global dynamics and the demands of the industry 4.0 era of work also emphasize the importance of human resources who are digitally competent, creative, innovative, and able to solve technical problems (Vitariyanti et al., 2024). Teachers are required to be more creative and avoid monotonous learning in order to overcome learning boredom and align the teaching process with students' diverse learning styles (Arifin et al., 2025). Therefore, the integration of technology-based pedagogical innovation is an absolute urgency to prepare graduates with relevant competencies to face future competition (Raziana & Wibawanto, 2025).

In reality, however, the HOTS achievement of Indonesian students remains critically low. PISA 2018 data placed Indonesia's mathematics score at 379, far below the OECD average of 487, with 71% of students failing to reach the minimum problem-solving competency (Yuniar et al., 2025). TIMSS 2011–2015 results further confirmed that Indonesian students are only capable of recognizing basic facts without the ability to relate or apply complex concepts. A study by Septiansyah et al. (2025) involving 98 students from high-achieving schools found that the percentage of students able to analyze was only at a moderate criterion, while their abilities to evaluate and create were very low. This performance gap stems from traditional or conventional learning approaches that lack variety and tend to be boring, making students less active during the learning process (Fitriani & Ridhani, 2025).

Similar problems were found in early childhood and informal education, where traditional approaches are deemed ineffective in accommodating children's holistic developmental needs (Nongko et al., 2025), and there is still a lack of appropriate control and guidance in the practice of using educational technology from an early age (Pinilih, 2023). In fact, higher-order reasoning-based assessments such as Computational Thinking (CT) and metacognition are still in their early stages of development (infancy), and metacognitive strategies are rarely taught explicitly (Buwono et al., 2025). On the other hand, science and biology learning at the secondary school level also faces similar challenges related to low higher-order thinking skills due to poorly structured digital learning management strategies (Sasongko et al., 2025).

Similar problems were also found at SMP Negeri 27 Surakarta. End-of-semester summative assessment (PSAS) data for the second semester of 2024/2025 showed average scores across all Grade VIII classes ranging from 68–69, slightly below the passing grade (KKM) of 70. A total of 32.26% of students had not met the KKM and experienced difficulties with visualization tasks such as calculating volume, surface area, and identifying components of geometric solids. Observations and interviews with mathematics teachers indicated that instruction was still dominated by the lecture method with conventional media that insufficiently facilitated the development of HOTS.

The topic of solid geometry has an abstract nature that requires spatial visualization skills. Conventional instruction without adequate visual representation makes it difficult for students to build connections between symbolic concepts and more concrete realities (Ridhani et al., 2025). The use of learning variations that integrate the latest media has proven to be the main key to building an inclusive, adaptive, and active classroom atmosphere (Arifin et al., 2025). Innovation efforts can be carried out through the implementation of problem-solving-oriented learning models. For example, the implementation of Problem-Based Learning (PBL) with a differentiated approach and the Zone of Proximal Development (ZPD) theory has been proven effective in increasing student activeness through active participation in discussions and independent task completion (Pawitra et al., 2025). Furthermore, the adoption of cloud computing technologies such as Google Forms, Quizizz, and Wordwall in assessments has also been proven to significantly increase the efficiency, effectiveness, and quality of student learning outcomes (Purnama et al., 2024). At the elementary education level, the development of multimodal digital interactive media based on Flipbook using Dick & Carey's instructional design has also been proven "very valid" and able to massively boost elementary school

students' problem-solving creativity (Yasni et al., 2025). This optimization effort is also in line with the crucial role of teachers in facilitating emotional intelligence (EQ) and character education such as honesty, responsibility, and cooperation in order to create a safe and supportive classroom environment for students' holistic development (Septyventia et al., 2024).

Accordingly, innovative learning media are needed to provide rich, interactive, and visual learning experiences. The post-pandemic shift in learning systems from face-to-face to screen-to-screen requires the use of educational technology to facilitate and improve learning outcomes (Peramtasari, 2023). One future trend promising a natural, immersive experience is the concept of the Metaverse, a 3D digital space that combines the real and virtual worlds (Alhakimi, 2023). Although the Metaverse offers new opportunities for education, its study from a pedagogical perspective is still rarely discussed (Alhakimi, 2023). As a pragmatic step before adopting a full-fledged virtual ecosystem like the Metaverse, Augmented Reality (AR) technology presents a highly relevant intermediary solution.

Augmented Reality (AR) is a technology that merges virtual objects into the real environment in real-time, enabling students to see and interact with three-dimensional objects directly through a smartphone (Rejekiningsih et al., 2023). Unlike Virtual Reality (VR), which fully replaces the real world, AR retains the real world as a backdrop and adds digital elements onto it. In the context of geometry learning, AR allows students to explore geometric solids in a manipulative and interactive way, thereby facilitating the knowledge-construction process consistent with Piaget's formal operational stage of cognitive theory and Mayer's multimedia learning principles.

Prior research has demonstrated positive impacts of AR on learning outcomes. Pujiastuti and Haryadi (2023) found that AR-based hybrid learning combined with innovative instructional models significantly improved students' higher-order thinking skills. A meta-analysis by Lu et al. (2025) confirmed the positive effect of AR on HOTS with a large effect size. A systematic review by Li et al. (2025) also showed that AR-based learning had a significant impact on learning outcomes and student engagement.

Based on the identified problems and literature review, this study aims to examine the effect of AR-based learning media on HOTS improvement among Grade VIII students at SMP Negeri 27 Surakarta in the topic of flat-sided solid geometry. The novelty of this study lies in the direct application of an AR application in classroom learning activities as part of the regular mathematics curriculum, as well as a comprehensive analysis of HOTS learning outcomes covering all three high-order cognitive aspects.

METHODS

Research Design

This study employed a quantitative approach with a quasi-experimental method using a pretest-posttest control group design. The experimental group received instruction using AR-based media, while the control group received conventional instruction. A pretest was administered before the treatment and a posttest after the treatment to measure HOTS improvement in both groups.

Table 1. Quasi-Experimental Research Design

Group	Pretest	Treatment	Posttest
Experimental	O ₁	X ₁ (AR Media)	O ₂
Control	O ₃	X ₂ (Conventional)	O ₄
Group	Pretest	Treatment	Posttest

Note: O = HOTS Test; X = Instructional Treatment

Population and Sample

The study was conducted at SMP Negeri 27 Surakarta during the 2025/2026 academic year. The research population consisted of all Grade VIII students across 6 classes. The sample was selected using purposive sampling based on the equivalence of prior academic ability, resulting in two classes: the experimental class (31 students) and the control class (32 students). The equivalence of initial ability between the two classes was confirmed through the previous semester's PSAS data and the pretest results, which showed no significant difference (a mean difference of only 0.07%).

Instruments and Data Collection Techniques

The primary research instrument was a reasoned multiple-choice HOTS test consisting of 21 items, measuring the ability to analyze (C4), evaluate (C5), and create (C6) on the topic of flat-sided solid geometry (cubes and rectangular prisms). The instrument was validated by two experts (a lecturer and a mathematics teacher) and piloted on a class outside the sample. Validity testing results showed that all items were valid, with adequate instrument reliability. Supporting data were collected through observations and interviews to describe the learning conditions.

Research Procedures

The study was carried out over approximately 4 weeks following these procedures: (a) instrument preparation and coordination with the school; (b) pretest administration in both classes; (c) treatment delivery over 5 sessions (@35 minutes each), the experimental class used an Android-based AR application to explore cubes and rectangular prisms visually and interactively, while the control class followed instruction using the lecture method and conventional media; (d) posttest administration; and (e) data analysis.

RESULTS AND DISCUSSION

Results

1. Pre-test and Post-test Descriptive Data

Prior to the treatment, both groups were at equivalent initial ability levels. The experimental class had a pretest mean of 35.79, while the control class had 35.86, with a difference of only 0.07%. After the treatment, the experimental class showed a drastic increase, reaching a post-test mean of 75.11, whereas the control class only reached 51.49.

Table 2. Descriptive Statistics of Pre-test and Post-test Data

Statistic	Pre-test Control	Pre-test Experimental	Post-test Control	Post-test Experimental
N	32	31	32	31
Highest Score	47.62	47.62	66.67	90.48
Lowest Score	23.81	23.81	38.10	57.14
Mean	35.86	35.79	51.49	75.11
Median	35.72	38.10	52.38	76.19
Std. Deviation	6.62	6.01	7.50	8.84

Source: Research data analysis (2026)

Table 2 shows a highly significant increase in the experimental class. The mean score rose from 35.79 (pre-test) to 75.11 (post-test), an increase of 39.32 points. In the control class, the increase was only 15.63 points (from 35.86 to 51.49). The post-test mean difference of 23.62 points between the two groups indicates the positive impact of AR media on students' HOTS.

2. Pre-requisite Analysis Tests

Before hypothesis testing, normality and homogeneity tests were conducted as prerequisites for parametric analysis.

Table 3. Shapiro-Wilk Normality Test Results

Data	Significance Value (Sig.)	Conclusion
Control Pretest	0.065	Normal
Control Posttest	0.101	Normal
Experimental Pretest	0.062	Normal
Experimental Posttest	0.086	Normal

Source: SPSS analysis results (2026)

The Shapiro-Wilk test results in Table 3 show that all significance values are >0.05 , indicating that the pre-test and post-test data in both groups are normally distributed. Subsequently, the Levene's homogeneity test yielded a significance value of 0.395 (>0.05), meaning the variance of data between the experimental and control classes was homogeneous. With both assumptions satisfied, the parametric analysis using the independent sample t-test could proceed.

3. Hypothesis Testing

Table 4. Independent Sample t-test Results

Group	N	Mean	Std. Deviation	t-value	Sig. (2-tailed)	Decision
Experimental	31	74.97	8.886	-11.348	<0.001	H ₀ Rejected
Control	32	51.53	7.466	-11.348	<0.001	H ₀ Rejected

Source: SPSS analysis results (2026)

Based on the independent sample t-test results in Table 4, a t-value of -11.348 was obtained with a significance of <0.001 . Because the significance value is <0.05 , H₀ is rejected and H₁ is accepted. It can be concluded that there is a statistically significant difference between the HOTS learning outcomes of the experimental and control classes. The mean difference of 23.44 points demonstrates the clear superiority of the group that used AR media.

4. N-Gain Analysis

Table 5. N-Gain Analysis Results

Group	N	Mean N-Gain (%)	Min	Max	Category
Experimental	31	60.31	25	86	Fairly Effective
Control	32	23.33	-19	54	Ineffective

Source: SPSS analysis results (2026)

Table 5 shows that the experimental class had a mean N-Gain of 60.31%, falling in the fairly effective category, while the control class only reached 23.33%, classified as ineffective. The minimum N-Gain value in the control class was even negative (-19), indicating that some students experienced a decline in learning outcomes. In contrast, all students in the experimental class showed improvement (minimum N-Gain of 25%). The mean N-Gain difference of 36.98% further reinforces the finding that AR media is more effective in improving HOTS than conventional instruction.

Discussion

The findings of this study consistently demonstrate that AR-based learning media exerts a positive and significant influence on students' HOTS improvement in the topic of solid geometry. These findings can be explained from several theoretical perspectives.

From the perspective of Piaget's cognitive theory, Grade VIII junior high school students are at the formal operational stage, which requires concrete representations to understand abstract three-dimensional geometry concepts. AR media can present geometric solid objects in three-dimensional form that can be virtually manipulated, thereby providing a more concrete and meaningful learning experience. This aligns with the characteristics of current digital multimedia developments, which integrate text, graphics, animation, and audio/video to enable users to navigate, interact, create, and communicate actively (Setyaningsih, 2023). Furthermore, in informal education and within the family environment, the introduction and control of digital technology from an early age have formed the foundation of digital habits, character, and adaptive behavior for the current generation of students (Pinilih, 2023). Through the presentation of manipulative objects in AR, students are helped to transcend the limitations of abstract visualization, similar to the success of the BERAKSI (Playing, Creating, Discussing, and Cheerful) learning model, which optimizes engagement and a fun learning atmosphere for better cognitive and social outcomes (Nongko et al., 2025). This condition encourages students to actively construct their knowledge through exploration, which is the core of Piaget's cognitive constructivism.

From the perspective of Mayer's Cognitive Theory of Multimedia Learning, the AR media developed in this study implements the principles of coherence, signaling, spatial contiguity, multimedia, and segmentation. The visualization of three-dimensional objects combined with labels and content explanations helps students connect visual information with verbal concepts simultaneously through two information-processing channels (visual and verbal), thereby optimizing cognitive processing and minimizing irrelevant cognitive load. The advantages of this interactive multimedia conditioning resemble the effectiveness of utilizing cloud computing technologies (such as Google Forms, Quizizz, and Wordwall), which can significantly improve the efficiency and quality of learning outcomes through instant feedback (Purnama et al., 2024). This strong integration of visual representations also addresses the needs of today's digital-era job market, where the ability to utilize digital services, understand applications, and solve technical problems are key assets for graduates' career development (Vitariyanti et al., 2024).

From a practical instructional perspective, the use of AR media transforms the learning paradigm from teacher-centered to student-centered. The theoretical and practical implications of these findings strengthen the synthesis of technology-based pedagogical innovations, such as the integration of AI and play-based strategies in creating inclusive and meaningful post-pandemic classrooms (Arifin et al., 2025). The success of AR in training higher-order cognitive skills is equivalent to the effectiveness of Game-Based Learning (GBL) pedagogical innovations—such as serious games and VR simulations—and the use of concrete media (such as globes and flashlights) in the Numbered Heads Together method, which has been proven to massively increase student motivation, conceptual understanding, logical skills, and academic performance (Fitriani & Ridhani, 2025; Raziana & Wibawanto, 2025). This structured AR-based teaching design provides important theoretical contributions, similar to the integration of digital platforms (such as Nearpod) developed with the Dick and Carey instructional design model to support higher-order cognitive processes through coherent digital learning management (Sasongko et al., 2025). Furthermore, adaptive visualization in AR also reflects the successful combination of the PBL model, differentiated instruction, and the ZPD in creating a motivating interactive learning environment based on students' initial abilities (Pawitra et al., 2025). This interactive interaction not only stimulates cognitive aspects but is also supported by the crucial role of teachers as facilitators and role models in integrating character values and strengthening students' emotional intelligence in the classroom (Septyventia et al., 2024).

Methodologically, the empirical findings in this study (N-Gain 60.31%) provide concrete answers to the challenges of current metacognitive and computational thinking assessments, which still lack validation through rigorous experimental methods and long-term interventions

(Buwono et al., 2025). The enhancement of spatial thinking skills through AR demonstrates that the design of digital interactive media systematically developed based on multimedia theory is valid and highly effective in supporting creative-critical thinking processes, making it highly relevant for adoption in 21st-century learning (Yasni et al., 2025). This also emphasizes the practical role of post-pandemic educational technology in optimally transforming the teaching landscape from face-to-face to screen-to-screen to improve student learning outcomes (Peramtasari, 2023). On a macro scale, the effectiveness of real-time visualization in AR validates the potential of future immersive technologies such as the Metaverse, which is predicted to provide a 3D digital space that blends with the real world to disrupt the way humans teach and learn in schools across the world (Alhakimi, 2023). Students are encouraged to actively explore geometric solids, analyze their components, evaluate the relationships between concepts, and even create visual hypotheses—processes that directly train all three HOTS aspects (C4, C5, C6). The high enthusiasm of students toward AR technology, combined with their background as digital natives accustomed to visual-interactive activities, also contributed to the effectiveness of the instruction.

These research findings are consistent with the results of Pujiastuti and Haryadi (2023), who demonstrated that AR-based hybrid learning significantly improved the HOTS of junior high school students. The meta-analysis by Lu et al. (2025) across various AR studies also confirmed the large positive effect of AR use on higher-order thinking skills. The systematic review by Li et al. (2025) further showed that AR in secondary education had a positive impact on higher-order cognitive learning outcomes.

Constraints identified in this study include students' limited smartphone devices, differences in device specifications, and internet network stability. This is an important note for larger-scale implementation, particularly in schools with limited technological infrastructure. Providing backup devices and organizing group learning arrangements can serve as practical solutions to overcome these barriers.

CONCLUSION

Based on the analysis and discussion, it can be concluded that the use of Augmented Reality (AR)-based learning media has a significant positive impact on improving students' Higher Order Thinking Skills (HOTS) in the geometry of flat surfaces. The interactive and manipulative three-dimensional visualizations in this technology have been proven to bridge abstract mathematical concepts into concrete representations, thus facilitating students' independent knowledge construction. Consequently, learning with AR media is far more effective in boosting students' higher-order thinking skills—especially in the areas of analysis, evaluation, and creation—compared to conventional approaches. This finding also addresses the initial problem in schools where mathematics learning activities are still dominated by lecture methods and the use of static media, which have not been able to optimally stimulate the development of students' critical reasoning skills. Theoretically and practically, the results of this study emphasize the importance of integrating immersive technology into digital learning management to create a 21st-century classroom ecosystem that is inclusive, adaptive, active, and problem-solving-oriented.

As a practical recommendation, mathematics teachers are advised to begin adopting and integrating AR-based media into their classroom learning plans, particularly for abstract topics that require advanced spatial visualization skills. To ensure optimal implementation of this technology, schools are expected to provide concrete support by providing adequate digital infrastructure, improving internet network stability, and facilitating teacher training to enrich their pedagogical offerings. Meanwhile, future researchers are advised to develop more comprehensive AR applications by integrating them with other innovative learning models—such as differentiated learning or game-based learning—and expanding the scope of trials across

different mathematics topics and educational levels to strengthen the validity and generalizability of this educational technology's effectiveness.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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The Effect of Web-Based Game Media (Earthgames) on Critical Thinking Skills in Earth Structure Learning for Junior High School Students

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ABSTRACT

This study investigates the effect of web-based game media, specifically Earthgames supported by the Wordwall platform, on the critical thinking skills of eighth-grade students in the topic of Earth Structure in the Natural Sciences (IPA) subject. A pre-experimental design using a one- group pretest-posttest approach was employed, involving 64 students from SMP Negeri 27 Surakarta during the 2025/2026 academic year. Data were collected through validated critical thinking tests covering indicators of interpretation, analysis, evaluation, inference, explanation, and problem-solving based on Facione's framework. Results showed a significant improvement in students' mean scores from 45.57 (pretest) to 67.27 (posttest). The hypothesis test using the Paired Sample t-test (Sig. < 0.001) confirmed a statistically significant difference, with an N- Gain score of 0.43 (moderate category). These findings indicate that Earthgames via Wordwall positively influenced students' critical thinking by providing interactive, visual, and game-based learning experiences. The media supports Mayer's Cognitive Theory of Multimedia Learning and aligns with the constructivist principles underpinning 21st-century science education.

Keywords: *Critical Thinking, Earthgames, Earth Structure, Science Learning, Web-based Game Media*



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INTRODUCTION

Facing the era of globalization and 21st-century technological advancement, education systems are increasingly required to develop higher-order thinking competencies, particularly critical thinking skills (Calma et al., 2025; OECD, 2020). Critical thinking enables students to not merely receive information passively but to analyze, interpret, evaluate arguments, and make logical decisions amid complex modern challenges (Calma et al., 2025). International educational organizations such as the OECD (2020) in the PISA framework and UNESCO (2016) in its Global Education Monitoring Report explicitly identify critical thinking as one of the 4Cs (Critical thinking, Creativity, Communication, Collaboration) that must be integrated into 21st-century learning. In Indonesia, PISA 2022 ranked the country 74th out of 79 nations in scientific literacy, reflecting persistent weaknesses in analytical and evaluative reasoning (OECD, 2022). This gap between 21st-century competency demands and actual IPA learning outcomes in Indonesia has been extensively documented (Kemdikbud, 2022).

In the theoretical context of science education, Facione (2021) defines critical thinking as a cognitive process involving interpretation, analysis, evaluation, inference, explanation, and self-regulation. Through these skills, students can interpret scientific data, evaluate hypotheses, formulate evidence-based arguments, and draw systematic conclusions. However, national assessment data shows that the competency of junior high school students in Indonesia is generally still at a basic level (Rahayu & Sugianto, 2021). This challenge is exacerbated by the fact that technological and information developments have drastically changed the landscape of learning media. Multimedia is no longer simply text and sound, but has evolved into a comprehensive combination of text, graphics, animations, images, and even audio/video, which have a tremendous impact on students' knowledge reconstruction (Setyaningsih, 2023). If these dynamic changes are not balanced with creative teaching variations, the classroom learning process will become monotonous, triggering boredom, and reducing student participation and motivation (Arifin et al., 2025). Therefore, the application of cutting-edge technological innovations, including the potential use of three-dimensional virtual spaces such as the metaverse, is now starting to be seen as a future trend to provide immersive and natural learning experiences in various educational institutions (Alhakimi, 2023).

At the classroom level, critical thinking development is hampered by teacher-centered instruction. Teachers remain the sole source of information while students passively receive knowledge (Paul, 2020). The reliance on static textbooks and worksheets further limits exploration, discussion, and problem-solving opportunities (Chen, 2024). This challenge is especially acute in IPA learning, where concepts require visualization, experimentation, and higher-level reasoning (Nugraha, 2023). Real-world conditions often demonstrate poor student understanding of science material due to unvaried and boring conventional teaching methods, which ultimately lead to passive and stifled students (Fitriani & Ridhani, 2025). However, the integration of digital technology, such as the use of cloud computing (Google Forms, Quizizz, and Wordwall), has been shown to significantly improve the efficiency, effectiveness, and quality of learning outcomes (Purnama et al., 2024).

The urgent need for well-designed interactive media has become a crucial focus in educational technology. The development of multimodal and adaptive digital learning media requires a solid foundation of instructional design models, such as the Dick & Carey Model, to ensure the media produced is valid, engaging, increases engagement, and effectively supports creative thinking and problem-solving (Yasni et al., 2025). Furthermore, systematically managing digital science learning using a clear instructional framework has been shown to be more effective in supporting students' higher-level cognitive processes than simply transmitting raw content (Sasongko et al., 2025).

To create an immersive, challenging, and meaningful learning environment, Game-Based Learning (GBL) has emerged as a highly promising innovative approach. Characteristics of GBL include clear goals and rules, scaffolded difficulty levels, real-time interactivity and feedback, and realistic contextual simulations (Mao et al., 2021; Wardani et al., 2023). A meta-analysis by Mao et al. (2021) confirmed that gamification significantly improved critical thinking skills (mean Hedges' g effect ≈ 0.7). Fatih et al. (2024) also demonstrated that digital educational games stimulate reflective analysis and evaluation in science learning. The use of GBL, such as serious games and VR simulations that integrate structured development models (e.g., ADDIE), has been shown to effectively increase motivation, engagement, and problem-solving skills (Raziana & Wibawanto, 2025).

One web-based interactive platform that facilitates this approach is Wordwall, which offers a variety of game formats such as quizzes, matching games, and crosswords that are easily adapted to various subject areas. Empirical research confirms that using Wordwall improves student engagement and cognitive outcomes in science (Saputra, 2021; Kurniawan, 2022). Based on this principle, this study developed Earthgames, a thematic game designed within the

Wordwall platform specifically for the Earth Structure topic, aligned with Facione's (2015) critical thinking indicators. Theoretically, this medium refers to Mayer's (2021) Cognitive Theory of Multimedia Learning, which states that learning is more effective when information is presented through visual and verbal channels simultaneously (the dual-channel principle), accompanied by appropriate cognitive load management (limited capacity) and active processing by learners. Through a combination of animation, graphics, and text-based interactive challenges, Earthgames helps students organize and internalize the Earth Structure concept more deeply.

Preliminary observations at SMP Negeri 27 Surakarta revealed that critical thinking skills among Grade VIII students remained low, with 62% experiencing difficulty explaining logical reasons, 54% struggling to analyze cause-effect relationships, and 65% lacking confidence in presenting systematic arguments. These findings underscore the urgent need for innovative, technology-based instructional media. While previous studies have widely explored the general use of web-based tools, there is still a significant research gap in how systematically designed, multimedia-theory-based educational games like Earthgames on Wordwall can directly impact all components of Facione's critical thinking indicators within abstract geoscientific topics. This research therefore aims to determine the effect of using Earthgames via Wordwall on the critical thinking skills of eighth-grade students at SMP Negeri 27 Surakarta in the IPA Earth Structure topic.

METHODS

Research Design

This study employed a quantitative approach using a pre-experimental one-group pretest-posttest design. This design was selected to measure changes in critical thinking skills within the same group of participants before and after the Earthgames intervention, providing empirical evidence of the media's effect (Creswell, 2020).

Participants

Participants were 64 eighth-grade students (Classes VIII A and VIII E) from SMP Negeri 27 Surakarta in the 2025/2026 academic year. Purposive sampling was applied based on criteria: prior exposure to Earth Structure content without digital interactive media, teacher-confirmed low critical thinking levels, and adequate device readiness for web-based media use.

Procedure

The study was conducted over four sessions: (1) Pretest administration; (2) Introduction and initial use of Earthgames via Wordwall; (3) Reinforcement of Earth Structure concepts through continued Earthgames activities; (4) Posttest administration. Students accessed the game through personal devices (smartphones or laptops) and engaged in quizzes, image-analysis tasks, and Earth Structure-based conceptual challenges.

Data Analysis

Descriptive statistics (mean, standard deviation) were computed for pretest and posttest scores. A normality test (Kolmogorov-Smirnov) confirmed normal data distribution (Sig. = 0.172 > 0.05), enabling the use of a Paired Sample t-test ($\alpha = 0.05$) for hypothesis testing. N-Gain analysis was conducted to assess the magnitude of improvement.

RESULTS AND DISCUSSION

Results

1. Pre-test results

The pretest mean score was 45.57 (SD = 12.74), with a minimum of 27.78 and a maximum of 66.67. The majority of students (37.5%) scored in the 31–40 interval, indicating that critical thinking skills were predominantly at a low-to-moderate level prior to the intervention.

Table 1. Pre-test Descriptive Statistics

No.	Statistic	Value
1	N	64
2	Highest Score	66.67
3	Lowest Score	27.78
4	Mean	45.57
5	Median	44.44
6	Std. Deviation	12.74

2. Post-test results

Following the Earthgames intervention, the mean posttest score increased to 67.27 (SD = 16.11), with a minimum of 38.89 and a maximum of 100. The majority of students (28.13%) scored in the 61–70 interval, reflecting a notable upward shift in performance distribution.

Table 2. Post-test Descriptive Statistics

No.	Statistic	Value
1	N	64
2	Highest Score	100
3	Lowest Score	38.89
4	Mean	67.27
5	Median	66.67
6	Std. Deviation	16.11

3. Normality test results

The Kolmogorov-Smirnov normality test yielded a significance value of 0.172 (> 0.05), confirming that the data were normally distributed. The Monte Carlo Sig. value of 0.102 further corroborated this finding, validating the use of parametric statistical analysis.

4. Hypothesis Testing (Paired Sample t-test)

The Paired Sample t-test revealed a significance value of Sig. (2-tailed) < 0.001 , which is well below the threshold of $\alpha = 0.05$. Consequently, H_0 was rejected and H_1 was accepted, confirming a statistically significant difference between pretest and posttest scores. This result indicates that the use of Earthgames via Wordwall had a significant effect on students' critical thinking skills.

Table 3. Paired Sample t-test Results

Variable	Mean Pre-test	Mean Post-test	Sig.	Decision
Pretest–Posttest	45.57	67.27	< 0.001	H_0 Rejected

4. N-Gain analysis results

The N-Gain value was calculated at 0.43 (43.03%), placing the improvement in the moderate category ($0.3 \leq g \leq 0.7$). This indicates that the Earthgames intervention contributed meaningfully to critical thinking development, though further refinement of instructional strategies and extended implementation periods could yield higher gains.

Discussion

The significant increase in critical thinking scores following Earthgames intervention supports the theoretical foundations of game-based learning and multimedia instruction. The mean improvement from 45.57 to 67.27 reflects gains across all Facione critical thinking indicators, particularly interpretation, analysis, evaluation, and inference.

These findings are consistent with prior research. Mao et al. (2021) found that gamification produces a substantial effect on critical thinking development (Hedges' $g \approx 0.7$). Similarly, Fatih et al. (2024) demonstrated that digital educational games for IPA significantly improved students' analytical and evaluative reasoning through reflective challenge-based learning. This finding is also in line with a study by Raziana & Wibawanto (2025) which confirmed that pedagogical innovation in the form of Game-Based Learning (GBL) which utilizes interactive game elements in authentic scenarios can significantly increase students' motivation, active engagement, and 21st-century skills such as logical thinking and problem-solving. This increase in cognitive performance proves that a dynamic and meaningful learning atmosphere can be created effectively when teachers creatively combine appropriate methods, media, and interactions to overcome student learning boredom in the classroom (Arifin et al., 2025).

The Wordwall platform, with its immediate feedback mechanisms and adaptive difficulty levels, enabled students to engage actively in Earth Structure concepts that are otherwise abstract and difficult to visualize. The success of the intervention using the Wordwall component in Earthgames reinforces the research findings of Purnama et al. (2024) regarding the effectiveness of utilizing cloud-based technology (cloud computing), which has been proven to have a real positive impact on learning efficiency and the quality of students' academic outcomes. This transformation of the learning process from conventional to interactive media has proven to be a crucial solution to classroom problems often encountered in science learning, where a direct learning model assisted by varied visual media is able to boost student learning completion in a classical manner compared to monotonous teacher teaching methods (Fitriani & Ridhani, 2025).

In alignment with Mayer's (2021) Cognitive Theory of Multimedia Learning, the dual-channel processing enabled by Earthgames—combining visual animations with text-based questions—facilitated deeper conceptual understanding. Students were not merely passive recipients of content but were required to analyze geoscientific phenomena, make predictions, and justify their reasoning, all of which are core components of critical thinking. The holistic nature of contemporary digital multimedia, which integrates text, graphics, animation, and audio/video, has been proven to have a significant impact on helping students independently reconstruct their knowledge across various educational institutions (Setyaningsih, 2023). Through dynamic visualization, the barriers to abstraction in complex geoscience material can be optimally reduced.

The learning outcomes achieved in this study are also inseparable from the systematic design of instructional management. As stated by Sasongko et al. (2025), the integration of digital platforms developed using formal instructional design models (such as the Dick and Carey model) significantly contributes to supporting students' higher-level cognitive processes, where structured digital learning management has been shown to be superior to simply transmitting content one-way. The validity and effectiveness of this visual game-based media are also supported by Yasni et al.'s (2025) argument that systematically developed multimodal digital media based on multimedia theory can support creative thinking processes and in-depth student learning engagement, making it highly relevant to the needs of 21st-century learning.

From a constructivist perspective, the interactive nature of Earthgames supported Vygotsky's (1978) social learning principles through scaffolded challenges and collaborative discussion. Students reported greater ease in connecting theoretical concepts—such as tectonic plate movement and seismic activity—with real-world phenomena after using the media, indicating meaningful learning experiences. This interactivity provides cognitive stimulation similar to the future vision of the use of immersive technologies such as the metaverse, where 3D digital spaces that blend the real and virtual worlds are projected to be able to provide new, natural and intuitive opportunities for global educational needs (Alhakimi, 2023).

The moderate N-Gain (0.43) is notable in the context of a relatively short intervention (four sessions) and a single-group design without a control comparison. The absence of a control group limits causal inference, as observed improvements could partly reflect natural learning progression or test-retest effects. Nevertheless, the statistically significant pre-post differences and the alignment with established theoretical frameworks provide strong evidence of Earthgames' utility as a critical thinking-enhancing media.

Technical limitations were also observed: internet connectivity issues intermittently disrupted media access for some students, a challenge prevalent in school settings in Indonesia. Future implementations should account for offline backup options or local network solutions to ensure equitable access. The experience of technical constraints and variations in students' cognitive responses in this study indicate the need for further exploration of more measurable mentoring strategies (nuanced scaffolding), strengthening instrument validity, and optimizing digital learning management systems as metacognitive tools to measure students' cognitive regulation authentically in the long term (Buwono et al., 2025).

CONCLUSION

This study concludes that Earthgames, as a web-based educational game integrated within the Wordwall platform, serves as an effective instructional media to enhance junior high school students' critical thinking skills in learning science, specifically on the topic of Earth Structure. The interactive, visual, and gamified features of the media provide an immersive learning experience that successfully stimulates core dimensions of critical thinking, including interpretation, analysis, evaluation, and inference. By transforming abstract geoscientific concepts into manageable cognitive challenges, the media minimizes conceptual barriers and shifts the classroom environment from passive absorption to active logical reasoning.

The theoretical and practical value of Earthgames directly aligns with Mayer's Cognitive Theory of Multimedia Learning and Facione's critical thinking framework, demonstrating that well-structured digital game-based learning supports 21st-century science competencies. Future educational implementations should expand this approach by employing experimental designs with control groups to isolate causal progress, extending the digital game formats across broader scientific themes and diverse grade levels, and adopting qualitative or performance-based evaluation instruments to fully map the deep, non-formal dimensions of students' reflective reasoning development.

CONFLICT OF INTEREST

The authors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Multimedia Development Android-based Learning of History at SMP Negeri 2 Paranggupito

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ABSTRACT

History learning at the junior high school level still faces several challenges, such as low student learning interest, dominance of lecture methods, and limited use of interactive learning media. These conditions make students difficult to understand chronology, cause-effect relationships, and historical events comprehensively. This study aims to develop Android-based learning multimedia for eighth-grade history subjects at SMP Negeri 2 Paranggupito and determine the feasibility of the media based on expert validation. This research used the Research and Development (R&D) method with the ADDIE development model consisting of analysis, design, development, implementation, and evaluation stages. The product was developed using Smart Apps Creator (SAC) in the form of an Android APK application containing historical materials, images, audio, animations, and interactive quizzes. Data collection techniques included observation, interviews, and validation questionnaires. The results showed that the Android-based learning multimedia obtained a "Very Good" category based on material expert and media expert assessments, indicating that the product was feasible for use in history learning. The Android-based multimedia learning application provides a more engaging, interactive, flexible, and relevant learning experience for digital generation students.

Keywords: *Learning Multimedia, Android, Smart Apps Creator, History, ADDIE*



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INTRODUCTION

Twenty-first-century education requires students to possess critical thinking, creativity, communication, and adaptability skills in response to the rapid development of digital technology. In this context, the use of instructional media has become an essential component in creating effective and meaningful learning experiences. Instructional media serves as a means of delivering information that helps students understand learning materials in a more concrete, engaging, and interactive manner (Arsyad & Hali, 2014). According to Mayer and Richard E. (2009), the use of multimedia in learning enhances student understanding by simultaneously integrating visual and verbal information. The current development of digital multimedia confirms that supporting technology is increasingly easy to use and is becoming a trend across regional boundaries (Setyaningsih, 2023). While previously limited to sound and text, multimedia has now undergone a massive transformation to include graphics, animation, video, and interactive links, triggering a shift in thinking about educational issues (Setyaningsih, 2023).

The urgency of utilizing interactive media is also driven by the shift in the educational landscape post-COVID-19 pandemic, where the learning process has shifted completely from face-to-face to screen-to-screen, which demands educators' mastery of digital science and technology to deliver meaningful content (Peramtasari, 2023; Pinilih, 2023). The use of cloud computing and digital platforms has been shown to improve learning efficiency at the vocational school level (Purnama et al., 2024), and future immersive technologies such as the Metaverse are also being explored for their potential to create natural 3D interaction spaces in various institutions worldwide (Alhakimi, 2023). Furthermore, the development of educational technology has also encouraged the use of adaptive and multimodal digital media to train critical thinking skills and problem-solving creativity (Yasni et al., 2025; Sasongko et al., 2025). Therefore, creative learning variations through interactive media are essential for teachers to eliminate boredom, embrace the diversity of student learning styles, and foster an inclusive classroom atmosphere (Arifin et al., 2025).

However, the reality on the ground reveals a significant gap. History instruction at the junior high school (SMP) level generally still faces significant challenges in the form of low learning interest, the dominance of conventional lecture methods, and limited variety of supporting media, resulting in low student learning outcomes (Fitriani & Ridhani, 2025). Based on initial observations at SMP Negeri 2 Paranggupito, history instruction was dominated by one-way lectures and the use of static printed textbooks, leading to student passivity and a lack of motivation. The abstract nature of historical content, which demands chronological reasoning and cause-and-effect relationships, often triggers misconceptions when presented without adequate visualization (Wahyudi, 2020). As a result, student engagement in classroom activities is minimal. Students' smartphone use has not been optimized for academic purposes, but is instead limited to non-instructional activities.

To address this gap, systematic pedagogical innovation is needed. One key alternative is designing interactive multimedia environments using measurable instructional design models such as ADDIE or Dick & Carey, which have proven valid in organizing digital content comprehensively (Yasni et al., 2025; Sasongko et al., 2025). Other innovative models, such as Game-Based Learning (GBL), using simulations or serious games, have also been shown to be effective in increasing intrinsic motivation and academic performance in the vocational education sector (Raziana & Wibawanto, 2025). Structured instructional approaches combined with visual media have been shown to significantly enhance students' conceptual understanding (Fitriani & Ridhani, 2025). Through the integration of Smart Apps Creator (SAC) software, teachers can produce interactive Android-based multimedia applications with APK extensions without the need for complex coding skills. This application can present text, audio, video, animation, and interactive quizzes in a single, flexible, user-friendly interface. Previous research confirms that Android-based learning media positively impacts student learning motivation (Hermansyah & Sari, 2020), while the use of interactive animations helps reconstruct historical imagination contextually (Hasan, 2024).

Based on the urgency and gaps, this research focuses on two main objectives, namely: (1) developing Android-based learning multimedia for the History subject of Class VIII at SMP Negeri 2 Paranggupito by systematically combining visual-verbal elements, and (2) testing the level of suitability of the media based on assessments from material experts and media experts in order to produce valid and relevant products for the characteristics of today's digital generation.

METHODS

This research method uses a Research and Development (R&D) approach, applying the ADDIE development model, which consists of five main stages:

1. **Analysis Phase:** The analysis phase was conducted to identify learning needs, characteristics of eighth-grade students, obstacles in history learning at SMP Negeri 2 Paranggupito, and the technical requirements for media devices. The analysis results showed that the majority of students already owned Android-based devices but had not yet utilized them as learning instruments.
2. **Design Phase:** The design phase included developing a competency map, creating a media flow storyboard, designing the user interface, navigation structure, selecting historical materials, and evaluating instruments in the form of interactive quizzes. The interface was designed to be simple for ease of use by junior high school students.
3. **Development Phase:** The development phase translated the storyboard design into Smart Apps Creator (SAC) software. The final output was an Android-based application with an APK extension that integrated text, historical visual illustrations, audio narration, animation, navigation buttons, and interactive quiz instruments.

RESULTS AND DISCUSSION

Results

1. Results of Multimedia Development

The product produced in this research is an Android-based multimedia learning application for History in grade VIII of junior high school. The application was developed using Smart Apps Creator (SAC) and packaged into an APK (Android Package) file format that can be installed directly on students' Android devices. The main menu components in this application include: a welcome page (splash screen), core and basic competency menus, history learning materials, a gallery of educational videos and animations, interactive quizzes, and a developer profile. The visual aspects harmoniously combine color composition, historical reconstruction images, audio narration, and animated transitions to optimize students' sensory stimulation during learning.

2. Subject Matter Expert Validation Results

Validation by subject matter experts focused on assessing the suitability of the material's substance with the applicable curriculum, the accuracy of historical chronology concepts, the systematic presentation of the material's sequence, and the readability of the linguistic aspects. Based on the tabulation of validation questionnaire data, the subject matter experts gave a qualitative rating of "Very Good" and declared the product suitable for classroom implementation. High ratings were obtained for indicators of alignment of learning outcomes and the accuracy of illustrations supporting abstract concepts. Some constructive input from the content experts included simplifying sentences in overly lengthy narrative descriptions and adding timeline infographics for certain historical events to strengthen the chronological structure.

3. Media Expert Validation Results

The validation by the media experts evaluated the quality of the interface design, navigation efficiency, level of interactivity, layout aesthetics, and ease of installation on mobile devices. The overall assessment by the media experts resulted in a "Very Good" category. Ease of operation and responsiveness of the menu buttons received optimal scores. Recommendations for improvement provided by the media experts included adjusting the contrast of the text font size on some background pages and optimizing the placement of the back button to prevent it from overlapping with the visual elements of the content.

Discussion

The findings of this research confirm that the developed Android-based learning multimedia is suitable and effective for use as an instructional medium in history teaching at the junior high school level. The application's ability to integrate text, visuals, audio, and interactive quizzes provides a multidimensional stimulus that can significantly improve student attention.

The theoretical implications of these results align with Mayer's Multimedia Learning Theory, which states that students' memory retention and conceptual understanding will develop optimally when information is processed through visual and verbal channels simultaneously. The integration of these digital multimedia elements reduces the cognitive overload caused by one-way text exposure (Mayer & Fiorella, 2021). Furthermore, the development of this interactive media with the APK extension addresses the challenges of multimedia modernization, which demands high flexibility, allowing users to navigate, create, and interact independently across spatial and temporal boundaries (Setyaningsih, 2023).

In the context of classroom management and student engagement, this Android-based media provides a solution to the problem of student boredom caused by monotonous lecture methods. As synthesized by Arifin et al. (2025), variations in learning through adaptive digital media have proven successful in building a dynamic, inclusive classroom climate that supports 21st-century skills. This effectiveness is also similar to the implementation of interactive digital platforms such as Nearpod, developed with structured instructional design, where significant improvements in students' higher-order thinking and critical analysis skills were observed (Sasongko et al., 2025). Through concrete visualizations, historical content initially perceived as abstract and boring can be transformed into contextual and engaging material, similar to the positive impact of using concrete media in improving student learning outcomes in the classroom (Fitriani & Ridhani, 2025).

This mobile technology innovation also offers the flexibility to use devices as self-regulated learning tools. When device use is properly controlled and supported through educational media, digital technology becomes the foundation for positive character and habits for the digital generation (Pinilih, 2023). This flexibility is also relevant to the principles of differentiated learning and the utilization of the Zone of Proximal Development (ZPD), where students can interactively learn material at their own pace (Pawitra et al., 2025). Furthermore, the integration of interactive quizzes within the SAC application provides instant feedback (formative assessment) that is essential for students' cognitive development, aligning with the urgency of technology-based metacognitive assessments that train planning, monitoring, and self-evaluation in problem-solving (Buwono et al., 2025).

Utilizing this media also contributes to students' readiness to face a more complex digital ecosystem. The introduction of Android-based media from elementary school helps foster digital literacy, technical problem-solving, and emotional management when interacting with media, which are crucial assets for future career development in the era of Industry 4.0 and the digital society (Septyventia et al., 2024; Vitariyanti et al., 2024). The integration of authentic scenarios and game elements within the interactive SAC quizzes also adopts the essence of Game-Based Learning (GBL) pedagogical innovation, which has been proven effective in triggering intrinsic motivation and in-depth understanding (Raziana & Wibawanto, 2025). Thus, Smart Apps Creator (SAC) has proven to be a highly applicable and efficient alternative instrument for teachers to produce independent mobile media to realize innovative transformations in history learning.

CONCLUSION

This research has successfully developed an innovative product in the form of an Android-based history learning multimedia application for eighth-grade students at SMP Negeri 2 Paranggupito, adopting the structured ADDIE instructional design model. This learning

multimedia was independently produced using the Smart Apps Creator (SAC) platform and produces an APK file that integrates text components, historical image visualizations, audio narration recordings, transition animations, and interactive evaluation quizzes. Assessments by both material and media experts consistently placed this product in the "Very Good" quality category, thus declaring this Android application valid and highly suitable for implementation in history learning in schools. This Android-based multimedia application has proven to be able to provide a more engaging, interactive, and flexible history learning experience, while also being a relevant solution for optimizing the potential of devices to increase the active engagement of digital-generation students.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Development of Animated Video Media to Improve Elementary School Students' Learning Comprehension

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ABSTRACT

This research is motivated by the lack of variety in the use of learning media in the subject of science and science on the topic of force in grade IV elementary school. The learning process is still dominated by lecture methods and the use of textbooks so that students are less active and have difficulty in understanding abstract material. Therefore, interesting and interactive learning media are needed to help students understand the material more easily. This research aims to: (1) develop Animaker-based animated video media on the topic of force for grade IV elementary school students, and (2) determine the level of feasibility of Animaker-based animated video media based on validation by material experts and media experts. This research is a research and development (R&D) using the ADDIE model limited to the analysis, design, and development stages. The analysis stage is conducted through observation, interviews, and learning needs analysis. The design stage includes the preparation of storyboards, materials, visual displays, and research instruments. The development stage is carried out by creating animated video media using the Animaker application and conducting media validation by material experts and media experts. Data collection techniques used observation, interviews, and validation questionnaires. The data obtained were analyzed using quantitative and qualitative descriptive analysis. The research results show that the Animaker-based animated video media for the topic of style was categorized as "Very Good" based on validation by material experts and media experts. The developed media was deemed appropriate for the learning outcomes and characteristics of elementary school students, and featured engaging visuals, audio, and animation. Animaker-based animated video media also helped students understand the topic of style more concretely and created a more active and enjoyable learning environment. Based on the research results, it can be concluded that the Animaker-based animated video media for style is suitable for use as a learning medium for fourth-grade elementary school science.

Keywords: *Animaker, Animated Videos, Learning Media, Science, Style Materials.*



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INTRODUCTION

Developments in educational technology have significantly impacted the learning process in elementary schools. The use of technology-based learning media is one way to create more engaging, interactive, and student-centered learning. Learning media plays a crucial role in helping teachers deliver material more concretely, making it easier for students to grasp the

concepts being studied. This development aligns with the view that learning media helps students construct knowledge in various educational institutions worldwide, where technology makes media increasingly easy to use (Setyaningsih, 2023). Today, digital multimedia integration no longer includes just voice and text, but also includes full text, graphics, animation, images, and audio/video, which has had a tremendous impact on shifting educational issues (Setyaningsih, 2023). However, the reality on the ground presents significant challenges. The learning process in elementary schools still largely relies on lectures and textbooks as the primary learning resources. This situation leads to a lack of student interest and difficulty understanding the material, especially abstract topics such as the topic of force in science. The problem of student boredom and low learning achievement is often caused by teachers' teaching methods that lack variety and tend to be boring (Fitriani & Ridhani, 2025). Teachers often teach conventionally, resulting in students becoming fixated and less active (Fitriani & Ridhani, 2025). This lack of variety creates an urgency for teachers to be more creative in combining methods, media, and interactions to create an inclusive, adaptive classroom atmosphere that supports 21st-century skills (Arifin et al., 2025).

The need for interactive and adaptive digital media to facilitate multimodal learning is growing (Yasni et al., 2025). Traditional approaches are often considered ineffective in accommodating students' holistic developmental needs, encompassing cognitive, social, emotional, and motor skills (Nongko et al., 2025). Therefore, innovative learning models are needed that can increase children's engagement in a fun atmosphere (Nongko et al., 2025), as well as the implementation of problem-based learning strategies combined with instructional differentiation to create an interactive and motivating learning environment for students (Pawitra et al., 2025). Teachers play a role not only as instructors but also as role models in shaping students' emotional intelligence and character by creating a safe and supportive classroom environment (Septiyentia et al., 2024). In today's digital era, mastery of digital technology and the ability to solve technical problems are important capacities that must be honed from an early age to be relevant to future demands (Vitariyanti et al., 2024). The use of advanced technologies such as shared virtual spaces or metaverses is even beginning to be developed to offer immersive and natural learning experiences as a future educational trend (Alhakimi, 2023).

Efforts to improve the quality of higher-level cognitive learning also require a systematic digital learning management strategy (Sasongko et al., 2025). The use of cloud computing-based technology has been proven to significantly improve the efficiency, effectiveness, and quality of student learning outcomes (Purnama et al., 2024). However, the use of this technology must not ignore the importance of appropriate guidance and control from an early age, considering that technology has become an integral part of the foundation for the formation of children's habits and character (Pinilih, 2023). On the other hand, conceptual challenges are still often encountered in digital learning assessments, particularly in authentically measuring cognitive regulation and metacognitive strategies (Buwono et al., 2025). This demands pedagogical innovations such as Game-Based Learning (GBL), which integrates systematic development models like ADDIE to increase motivation, engagement, and problem-solving skills (Raziana & Wibawanto, 2025). Educational technology also plays a vital role in facilitating post-pandemic screen-to-screen learning to improve learning outcomes according to students' needs and characteristics (Peramtasari, 2023).

Animated videos are a learning medium that can be used to help students understand material more concretely. Animated videos combine visual, audio, text, and animation elements, making learning more engaging and easier for students to understand. The use of animated videos also aligns with the characteristics of elementary school students, who tend to prefer interactive and colorful visual displays. Animaker is a digital-based application that can be used to create interactive and easy-to-use animated learning videos. This application

provides various features such as character animation, illustrations, audio, scrolling text, and visual effects to support the learning process. In this study, an animated video was developed using the Animaker application on the topic of stylistics for fourth-grade elementary school students. The developed media is equipped with subtitles, practice exercises, and reflective questions to encourage students to be more active in the learning process. This study aims to develop Animaker-based animated video media on the topic of stylistics for fourth-grade elementary school students and to determine the media's suitability based on validation results from media experts and material experts.

METHODS

This research used the Research and Development (R&D) method with the ADDIE development model, which includes analysis, design, and development stages. The ADDIE model was chosen because it has systematic stages and is easy to apply in developing learning media.

Analysis Phase

The analysis phase was conducted to identify learning needs, student characteristics, learning materials, and learning conditions at SD Negeri 4 Jatisrono. Observations showed that learning was still dominated by lecture methods and the use of textbooks, resulting in a lack of student engagement. Furthermore, students needed more engaging and interactive learning media to facilitate their understanding of the science material.

Design Phase

The design phase included formulating learning objectives, developing storyboards, designing visual displays, preparing learning materials, audio narration, and evaluation instruments. The media was designed using bright colors, engaging animated characters, and concise text to suit the characteristics of elementary school students.

Development Phase

The development phase was carried out by creating animated video media using the Animaker application. The resulting product was an MP4-format animated video containing force material, animated illustrations, audio narration, explanatory text, examples of real-life events, and reflective quizzes. At this stage, validation by material experts and media experts was also conducted to determine the feasibility level of the learning media. Data collection techniques included observation, interviews, documentation, and validation questionnaires. The research instrument employed a Likert scale to assess the feasibility level of the media based on evaluations from material experts and media experts.

RESULTS AND DISCUSSION

Results

1. Results of the Animated Video Media Development

The product developed in this study was an animated learning video on the topic of force for fourth-grade elementary school students. The media was created using the Animaker application in MP4 format, allowing it to be played on laptops, projectors, and smartphones. The animated video consisted of several main sections, namely the opening page, presentation of learning objectives, force material, animated illustrations, reflective quizzes, and closing section. The material presented included muscular force, frictional force, spring force, magnetic force, and gravitational force. The media was designed with an attractive visual appearance using a combination of bright colors, animated characters, concise text, and audio narration. In addition, the animated video media was equipped with subtitles and highlighted important text to help students understand concepts more easily. The material was presented gradually so that students could follow the learning process effectively.

2. Results of Material Expert Validation

Material expert validation was conducted to assess the suitability of the material content with the curriculum, conceptual accuracy, systematic presentation, and language usage. Based on the validation results, the animated video media obtained a “Very Good” category and was declared feasible for use in learning activities. The aspects assessed included: (1) Suitability of the material with learning outcomes, (2) Accuracy of force concepts, (3) Clarity of material presentation, (4) Suitability of learning evaluation, and (5) Use of communicative language. The material expert also provided several suggestions for improvement, such as simplifying sentences and adding contextual examples to make the material easier for students to understand.

3. Results of Media Expert Validation

Media expert validation was conducted to evaluate aspects of visual appearance, layout, interactivity, audio quality, animation, and ease of media use. The validation results indicated that the animated video media achieved a “Very Good” category. The aspects assessed included: (1) Visual appearance of the media, (2) Suitability of colors and layout, (3) Quality of audio and narration, (4) Suitability of animations, (5) Ease of media use, and (6) Suitability of the media with student characteristics. The media expert suggested adjusting the font size and optimizing animation transitions to improve viewing comfort.

Discussion

The findings of this study indicate that animated video media is feasible to be used as a learning medium for science subjects in elementary schools. The use of animated videos provides a more engaging learning experience because the material is presented through a combination of visual and audio elements simultaneously. These findings are consistent with Mayer's Multimedia Learning Theory, which states that students can understand material more easily when information is delivered through visual and verbal channels simultaneously. The use of animations, images, text, and audio narration helps students understand abstract concepts in a more concrete way. In addition to improving learning comprehension, animated video media also increases students' attention and learning motivation. Students become more actively involved in learning activities because the media presentation is attractive and not monotonous. The reflective quizzes included in the video also help students identify their level of understanding directly.

The implications of these findings strengthen the urgency of using integrated digital multimedia which is capable of presenting text, animation, images and audio simultaneously in order to encourage major changes in the effectiveness of science learning (Setyaningsih, 2023). The successful development of this Animaker-based animated video aligns with the effectiveness of interactive digital media based on systematic instructional design models—such as the Dick & Carey and ADDIE models—which have been shown to significantly increase student engagement and support creative thinking in 21st-century learning (Yasni et al., 2025). Through dynamic visual presentation, this animated video overcomes the weaknesses of conventional approaches, which tend to be monotonous and under-facilitate children's developmental needs (Nongko et al., 2025). Furthermore, the use of media combined with interactive methods has been shown to reverse the low classical student mastery levels caused by boring teaching methods, leading to optimal scientific understanding (Fitriani & Ridhani, 2025). The active engagement generated by the reflective quizzes in this media also supports the creation of a motivated learning environment, similar to the positive outcomes of the Problem-Based Learning model supported by differentiation (Pawitra et al., 2025).

From an educator perspective, teachers' development of independent media using applications like Animaker demonstrates that varied teaching through creative media

integration and interaction is key to reducing classroom boredom (Arifin et al., 2025). This also facilitates teachers in strengthening their role in the digital classroom, not only as content deliverers but also as facilitators who build emotional closeness and a supportive environment for students (Septyventia et al., 2024). In the modern era, students' ability to respond to digital technology-based media is a crucial initial asset for developing technical intelligence and future career readiness (Vitariyanti et al., 2024). In the long term, the development of interactive animated videos even lays the foundation for the adoption of more sophisticated and immersive educational technologies such as 3D virtual spaces or the metaverse (Alhakimi, 2023). The structured digital instructional management of Animaker videos reinforces the theory that systematic digital content management has a significant impact on improving students' higher-level cognitive processes (Sasongko et al., 2025).

The implementation of this media also emphasizes the benefits of the efficiency and effectiveness of digital technology in the classroom, such as the use of cloud computing-based technology that optimizes learning outcomes (Purnama et al., 2024). However, the use of digital media in elementary school children must still be accompanied by appropriate control and guidance from educators, so that character formation and learning habits in the digital era are meaningful (Pinilih, 2023). The development of this Animaker-based media also offers an alternative solution to conceptual challenges in digital assessment by providing reflective quizzes directly within the video, which helps bridge the gap in formative evaluation of students' cognitive regulation (Buwono et al., 2025). The product development structure, packaged through interactive visual elements, reflects authentic scenario-based pedagogical innovations such as Game-Based Learning, which has been proven successful in triggering motivation and problem-solving skills (Raziana & Wibawanto, 2025). Ultimately, the transformation from conventional learning to screen-to-screen media emphasizes the role of educational technology in facilitating and improving the quality of learning outcomes relevant to the characteristics of today's generation of learners (Peramtasari, 2023). The use of the Animaker application has proven to facilitate teachers' independent and sustainable production of digital learning media.

CONCLUSION

Based on the study results, it can be concluded that this study successfully developed an animated video learning media on the topic of force for fourth-grade students of SD Negeri 4 Jatisrono using the ADDIE development model. The animated video media was developed using the Animaker application in MP4 format, containing learning materials, visual illustrations, animations, audio narration, subtitles, and reflective quizzes. The results of material expert and media expert validations indicated that the animated video media obtained a "Very Good" category and was therefore considered feasible for use in the learning process. The animated video media was able to help improve students' learning comprehension through the presentation of material in a more concrete, engaging, and interactive manner. Furthermore, this multimedia integration provides strong theoretical and practical implications in bridging the gap between limited teaching variations and teachers, increasing motivation, and supporting the strengthening of 21st-century cognitive skills through systematic management of educational technology.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Analysis of Teacher Readiness Based on UTAUT2 in Utilizing Interactive Multimedia at State Madrasah Tsanawiyah in Bekasi Regency

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ABSTRACT

This study analyzes teachers' readiness to utilize interactive multimedia in learning at State Islamic Junior Secondary Schools (MTsN) in Bekasi Regency using the Unified Theory of Acceptance and Use of Technology 2 (UTAUT2) framework. The research employed a quantitative descriptive approach with 63 teachers as respondents selected through total sampling technique. Data were collected using a Likert scale questionnaire instrument comprising nine UTAUT2 constructs: performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, habit, behavioral intention, and use behavior. Results indicate that overall teacher readiness is at a high level with a mean score of 4.06. Performance expectancy achieved the highest score (M=4.34), followed by behavioral intention (M=4.27), hedonic motivation (M=4.07), effort expectancy (M=4.03), use behavior (M=3.98), and social influence and facilitating conditions (M=3.88 each). These findings demonstrate that teachers at MTsN in Bekasi Regency possess sufficient cognitive, technical, social, environmental, and motivational readiness to adopt interactive multimedia. The study contributes empirical evidence for applying UTAUT2 in Islamic education contexts and provides a strategic foundation for the Ministry of Religious Affairs in designing targeted teacher competency development programs.

Keywords: *Interactive Multimedia, Madrasah Tsanawiyah, Teacher Readiness, Technology Adoption, UTAUT2*



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INTRODUCTION

Education plays a crucial role in preparing competent human resources capable of competing in the face of global challenges. Fansury et al. (2025) assert that quality education not only teaches foundational knowledge but also equips students with relevant skills to navigate global demands. As technology advances rapidly, the education sector must adapt and harness technology to improve learning quality. The use of information and communication technology (ICT) in education continues to expand and is regarded as one of the key factors in enhancing the quality of teaching and learning processes (Song et al., 2025)

The global educational paradigm has shifted significantly from mere cognitive achievement toward the mastery of 21st-century skills such as digital literacy, collaborative ability, and creativity. In response to these demands, the Ministry of Religious Affairs strengthened the legal framework for madrasah education through Ministerial Decree Number 347 of 2022 on the Implementation of the Merdeka Curriculum in Madrasah. This regulation explicitly mandates

that learning in madrasah must become more dynamic, competency-oriented, and character-based through Project Based Learning (Kementerian Agama RI, 2025)

Within this Merdeka Curriculum framework, technology is positioned as a primary pillar for pedagogical innovation. Interactive multimedia—integrating text, audio, video, and animation—is no longer merely a visual aid but a crucial strategy for creating immersive and relevant learning experiences in the digital era (Mayer, 2024). According to Sari et al. (2021), interactive multimedia is a learning medium combining text, images, sound, video, animation, and interactivity, presented through computer software or digital applications that allow students to directly interact with learning content rather than passively receiving it.

A preliminary study conducted on August 6, 2025 at MTsN 2 Bekasi Regency revealed a sharp gap between curriculum demands and teacher competency realities. Of 44 active teachers, 35 (80%) had conceptual understanding of interactive multimedia, yet only 9 (20%) consistently implemented it in daily teaching. More critically, only 1 teacher (approximately 2%) had reached an innovative level—independently developing digital teaching materials. This data confirms that theoretical understanding has not been transformed into practical skills (Lestari et al., 2024)

Several factors contribute to this condition. First, limited technical training causes some teachers to understand theory without being able to independently create digital media. Second, school facility constraints, including inadequate computers and internet networks. Third, strong conventional teaching habits reduce teacher motivation to innovate (Suyanto et al., 2024). This is reinforced by Manurung & Panggabean (2020), who state that most Indonesian teachers still rely on traditional approaches and have not fully transitioned to more interactive and contextual digital media.

According to Shurygin et al. (2022), teacher readiness to implement digital technology is strongly influenced by three main aspects: knowledge of technology, skills in its use, and attitudes or acceptance toward technological innovation. Additionally, Schmid & Petko (2019) emphasize that even when technological infrastructure is provided in schools, teacher reluctance to use technology in classrooms reflects that readiness is not solely determined by technical capability, but also by attitudes and available environmental support.

The UTAUT2 (Unified Theory of Acceptance and Use of Technology 2) can serve as a framework for understanding factors reflecting teacher readiness and acceptance of technology. According to Venkatesh et al. (2012), UTAUT2 builds upon UTAUT by adding hedonic motivation, price value, and habit constructs, making it more appropriate for individual user contexts. Based on research by Tseng et al. (2022) UTAUT2 proves to be a more appropriate model in the context of technology adoption by teachers, particularly in online learning systems. Furthermore, Sukmawati et al. (2024) explain that UTAUT2 encompasses seven distinct factors influencing behavioral intention (BI) or use behavior (UB): performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and habit.

Previous studies reveal significant research gaps. Haris et al. (2019) applied UTAUT2 to evaluate the Ruang Guru application, but their subjects were secondary school students, not teachers. Yarun et al. (2023) examined interactive multimedia in MTs settings using a qualitative descriptive approach, which does not measure readiness based on UTAUT2 constructs. Allutfia & Setyaningsih (2023) focused on teacher readiness but primarily for the new Merdeka Curriculum, not the psychological aspects of digital technology adoption. Accordingly, Kittinger & Law (2024) through a systematic review of UTAUT and UTAUT2 among K-12 educators confirm that specific research measuring State Islamic Junior Secondary School teacher readiness using complete UTAUT2 constructs, particularly in Indonesia's madrasah context, remains scarce.

This research is therefore significant in providing deep understanding of teacher readiness to meet continuously evolving digital learning demands, specifically in the context of utilizing interactive multimedia in madrasah. Results are expected to contribute both theoretically—validating UTAUT2 applicability in Islamic school contexts—and practically, by providing

strategic foundations for the Ministry of Religious Affairs in designing targeted, empirically grounded teacher competency development programs.

METHODS

Research Design

This study employed a quantitative descriptive approach. According to García Murillo et al. (2023), the quantitative descriptive approach is suitable for measuring and describing technology acceptance phenomena using validated theoretical frameworks. The UTAUT2 model served as the analytical framework, enabling systematic and comprehensive measurement of all constructs that describe teacher readiness in utilizing interactive multimedia.

Participants

The research population consisted of all teachers at State Madrasah Tsanawiyah (MTsN) in Bekasi Regency. Total sampling technique was employed, yielding 63 teacher respondents across MTsN institutions in Bekasi Regency. Ayanwale et al. (2022) emphasize that total sampling is appropriate when the population is limited and accessible, ensuring representative and valid data. The demographic characteristics of respondents are presented in Table 1.

Table 1. Respondent Demographics

Variable	Category	n	%
Gender	Male	24	38.1
	Female	39	61.9
Age	≤ 30 years	12	19.0
	31–40 years	27	42.9
	41–50 years	18	28.6
	> 50 years	6	9.5
Education	Bachelor's (S1)	51	81.0
	Master's (S2)	12	19.0
Teaching Experience	< 5 years	15	23.8
	5–10 years	24	38.1
	> 10 years	24	38.1

Source: Primary Data, 2026

Instrument

Data were collected using a questionnaire instrument comprising 45 statements measured on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The instrument covered nine UTAUT2 constructs: performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating conditions (FC), hedonic motivation (HM), price value (PV), habit (HA), behavioral intention (BI), and use behavior (UB). Instrument items were adapted from Venkatesh et al. (2012) and further developed according to the interactive multimedia context in madrasah learning.

Validity and Reliability

Content validity was assessed through expert review and Pearson correlation analysis with $r_{table} = 0.248$ ($n=63$, $\alpha=0.05$). All items showed $r_{count} > r_{table}$, indicating valid instruments. Reliability was measured using Cronbach's Alpha, yielding coefficients ranging from 0.786 to 0.891 for all constructs, exceeding the 0.70 threshold and confirming high instrument reliability (Scherer et al., 2019).

Data Analysis

Data analysis utilized descriptive statistics by calculating the mean scores for each construct and the overall readiness level. The interpretation of mean scores was conducted using a 5-point Likert scale classification to determine respondents’ readiness levels. The interval classification was calculated using the following formula:

$$\begin{aligned} \text{Interval Width} &= \frac{\text{Highest Score} - \text{Lowest Score}}{\text{Number of Categories}} \\ &= \frac{5 - 1}{5} \\ &= 0.80 \end{aligned}$$

Based on the interval calculation above, the score interpretation criteria were categorized into five levels ranging from “Very Low” to “Very High.” Meanwhile, the UTAUT2 framework proposed by Venkatesh et al. (2012) was used as the theoretical basis for analyzing factors influencing teachers’ readiness in adopting interactive multimedia technology.

Table 2. Score Interpretation Criteria

Score Range	Category	Readiness Level
4.21 – 5.00	Very High	Very Ready
3.41 – 4.20	High	Ready
2.61 – 3.40	Moderate	Fairly Ready
1.81 – 2.60	Low	Less Ready
1.00 – 1.80	Very Low	Not Ready

Source: Developed by the researcher based on 5-point Likert scale interval interpretation.

RESULTS AND DISCUSSION

Results

Descriptive analysis of all UTAUT2 constructs showed that overall teacher readiness in utilizing interactive multimedia at MTsN in Bekasi Regency was at a high level (M=4.06). Table 3 presents the complete descriptive analysis results for all nine constructs.

Table 3. Descriptive Analysis Results of UTAUT2 Constructs

Construct	Mean	Std. Dev.	Category
Performance Expectancy	4.34	0.51	High
Effort Expectancy	4.03	0.58	High
Social Influence	3.88	0.62	High
Facilitating Conditions	3.88	0.59	High
Hedonic Motivation	4.07	0.55	High
Price Value	4.01	0.57	High
Habit	3.95	0.63	High
Behavioral Intention	4.27	0.49	High
Use Behavior	3.98	0.60	High
Overall	4.06	0.57	High

Source: Primary Data, 2026

Discussion

Performance Expectancy (M=4.34) achieved the highest score among all constructs, indicating that teachers strongly believe interactive multimedia can enhance teaching

effectiveness. This is consistent with the UTAUT2 theoretical framework, where Venkatesh et al. (2003) define performance expectancy as an individual's belief that using a technology system can provide real benefits in improving job performance. High performance expectancy reflects teachers' cognitive readiness in assessing the benefits of multimedia for student learning outcomes. This finding aligns with Hanan Pratiwi et al. (2024), who assert that using interactive multimedia can increase student engagement, encourage active participation, and help comprehend abstract or complex material more concretely.

The theoretical foundation supporting this finding is Mayer (2024) Cognitive Theory of Multimedia Learning (CTML), which explains that effective interactive multimedia should be designed to maximize students' cognitive capacity. Munaji et al. (2025) further confirm that teachers' belief that technology can improve learning effectiveness directly correlates positively with their readiness to integrate it. Similarly, Acosta-Enriquez et al. (2024) through UTAUT2-based research on technology acceptance in university contexts find that performance expectancy consistently becomes the strongest predictor of behavioral intention across various educational technology contexts.

Effort Expectancy (M=4.03) indicates that teachers consider interactive multimedia relatively easy to understand and operate. This construct reflects technical readiness and self-confidence in operating learning technology. According to Venkatesh et al. (2003) effort expectancy is defined as the degree of ease associated with the use of a system, referring to how much the system is considered easy to understand and operate. High effort expectancy suggests that interactive multimedia does not constitute a significant barrier in the technology adoption process.

From the perspective of Information Processing Theory, effort expectancy plays a crucial role in minimizing cognitive load on teachers' working memory when operating technology (Backfisch et al., 2021). Kavitha & Joshith (2024) and Yang (2025) note that ease of use can be contextual and influenced by infrastructure readiness and media design. This suggests that although effort expectancy is high, supporting conditions such as facilities and technical support remain important aspects in maintaining technology ease of use.

Social Influence (M=3.88) demonstrates that teachers perceive social support in using interactive multimedia. Venkatesh et al. (2012) define social influence as the extent to which individuals perceive that important people around them encourage the use of a technology. High scores on this variable indicate teachers are not in isolated individual conditions but operate within social environments supporting interactive multimedia use. This supports findings by Lisana (2022) and Surya et al. (2021) showing that social environment support, including peers and professional communities, frequently strengthens tendencies toward digital technology use.

Facilitating Conditions (M=3.88) reflects that teachers have access to resources, infrastructure, and technical support needed for interactive multimedia use. This aligns with Clark et al. (2024) and Welle et al. (2021), who show that infrastructure availability and technical support represent important aspects of environmental readiness for technology use. Selection of MTsN institutions—which have relatively standardized government-provided facilities—ensures more homogeneous facilitating conditions, making the UTAUT2 measurement more focused on psychological and perceptual aspects rather than infrastructure disparities.

Nonetheless, Carvalho & Santos (2022) emphasize that facility availability alone is insufficient without ongoing support, including training and consistent organizational policies.

Hedonic Motivation (M=4.07) indicates teachers experience attraction, comfort, and enjoyable experiences in using interactive multimedia. Venkatesh et al. (2012) define hedonic motivation as the level of enjoyment or satisfaction individuals experience when using technology. This finding is consistent with Du & Liang (2024) and Zhang et al. (2022), who show that enjoyable technology experiences can strengthen usage tendencies in digital learning contexts. Moorthy et al. (2019) additionally confirm that habit and hedonic motivation are the strongest influences on mobile learning behavior among higher education students, a finding relevant to this research context where technology engagement provides intrinsic satisfaction beyond mere pedagogical obligation.

Price Value (M=4.01) shows that teachers view interactive multimedia as providing greater benefit than the effort or cost required. According to Venkatesh et al. (2012), price value refers to the cognitive tradeoff between perceived benefits and monetary cost of using technology. In the educational context, price value relates to perceived value of time, energy, and resources invested in developing interactive multimedia. High price value suggests teachers perceive this investment as worthwhile—consistent with Rondan-Cataluña et al. (2015), who confirm that UTAUT2 has the highest predictive rate compared to other technology acceptance models including TAM variants, largely because it captures this economic reasoning alongside hedonic factors.

Habit (M=3.95) demonstrates that technology use, particularly interactive multimedia, has begun to become a teaching habit for teachers. From the Information Processing Theory perspective, habit formation reflects successful encoding of procedural knowledge into long-term memory (Kholifah et al., 2024). Tian et al. (2022) show that when users have regularly used technology over a certain period, such use becomes automatic and sustainable. The role of habit is particularly important in this madrasah context because Arwildayanto et al. (2023) emphasize that in-service training and continuous professional development (CPD) programs play an important role in forming professional teachers ready to face educational challenges—ultimately building the habit structures that UTAUT2 measures.

Behavioral Intention (M=4.27) indicates teachers have strong intention to continue using interactive multimedia in future learning. In the UTAUT2 framework, Venkatesh et al. (2012) explain that behavioral intention is a core construct describing an individual's desire or intention to use technology. This finding aligns with Awaluddin et al. (2022) and Alviani et al. (2023), who show that behavioral intention is frequently influenced by performance expectancy, effort expectancy, social influence, facilitating conditions, hedonic motivation, price value, and habit. Strzelecki (2023) and Dinh et al. (2025) further confirm that hedonic motivation and habit have important roles in strengthening behavioral intention, particularly in contexts where technology adoption is voluntary rather than mandated.

Use Behavior (M=3.98) demonstrates that teachers have actually used interactive multimedia in learning processes, indicating that readiness has moved beyond intention to become actual practice. Zhang et al. (2022) state that the behavioral intention → use behavior relationship pathway is the most consistent pattern in UTAUT2 research, particularly in mobile learning and multimedia learning contexts. Mittal et al. (2021) additionally show that in digital

learning contexts, sustained technology adoption occurs when individuals have high intention and have become accustomed to using technology in learning activities. The finding of use behavior at MTsN in Bekasi Regency aligns with Domingueti et al. (2022) who find that user experience with interactive simulation-based learning systems can increase actual technology use when systems are easy to operate and provide clear benefits.

Overall, the finding that all nine UTAUT2 constructs are at a high level provides empirical evidence that the UTAUT2 model is valid for measuring teacher technology readiness in Islamic educational institution contexts—a contribution aligned with calls from Ates & Polat (2025) for broader application of UTAUT2 in diverse educational settings. The study also confirms Peters et al. (2022) view that digital competency development for teachers should not be conducted through one-time training alone, but needs to be strategically designed, institutionally integrated, and ongoing for more significant impact on learning practice. Furthermore, Pavlou & Burke (2025) and Rahimi & Teimouri (2025) reinforce that in online learning eras, there is an urgent need to develop effective learning design, pedagogy, and digital competencies in educators—underscoring the policy relevance of this study's findings for the Ministry of Religious Affairs.

When compared to previous studies, this research shows consistency and differences. Kittinger & Law (2024) through a systematic review of UTAUT and UTAUT2 among K-12 educators confirm that teacher readiness factors identified in this study—performance expectancy, facilitating conditions, and social influence—are the most frequently significant constructs in educational technology adoption. However, this study adds novelty by specifically measuring hedonic motivation and habit in the Islamic madrasah context, constructs those previous studies in similar Indonesian educational contexts had not fully explored. The convergence across constructs also echoes Ainul Bashir (2020) and Daud Mahande & Jasruddin (2018) who's Indonesian UTAUT-based studies consistently show high performance expectancy and social influence as dominant drivers of educational technology acceptance.

The practical implication of these findings is that teacher readiness improvement programs should focus not only on technical skills but also on strengthening psychological aspects such as motivation, positive attitudes, and technology use habits. Moriña & Perera (2025) and Winícius et al. (2023) note that technology learning experiences occurring outside formal contexts (such as personal experience) can be key in forming more comprehensive teacher readiness to integrate technology in formal classrooms. The school's role in creating conducive facilitating conditions—as demonstrated by Lan (2024)' research on technology-enhanced teacher training—remains essential for sustaining the high readiness levels observed in this study.

CONCLUSION

This study concludes that overall teacher readiness to utilize interactive multimedia at State Madrasah Tsanawiyah in Bekasi Regency is at a high level, reflecting that teachers possess sufficient cognitive, technical, social, environmental, and motivational readiness to adopt interactive multimedia. All nine UTAUT2 constructs—performance expectancy, behavioral intention hedonic motivation, effort expectancy, price value, use behavior, habit, social influence, and facilitating conditions—are at high levels, confirming that teacher readiness is not merely conceptual but has been reflected in actual practice in the field.

This research contributes empirical evidence for the applicability of UTAUT2 in Islamic educational institution contexts in Indonesia. The study fills a literature gap by specifically measuring MTsN teacher readiness using complete UTAUT2 constructs, including hedonic motivation and habit variables that have not been widely explored in Indonesian madrasah settings. Practically, these findings provide a strategic foundation for the Ministry of Religious Affairs in designing targeted, empirically grounded teacher competency development programs encompassing not only technical aspects but also psychological and behavioral adaptation.

Future research is recommended to extend analyses using inferential approaches or structural equation modeling (SEM) to examine causal relationships between UTAUT2 constructs. Expanding the research scope to include private madrasah in Bekasi Regency would provide comparative insights, and incorporating mixed methods designs would yield deeper qualitative understanding of the motivational and cultural factors underlying the readiness levels documented here.

CONFLICT OF INTEREST

The authors declare no conflict of interest related to the research, authorship, or publication of this article.

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The Effect of Flipped Classroom Learning Model on Psychomotor Learning Outcomes in Prototype Design for Class X Students at SMK Negeri 1 Sawit Boyolali

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ABSTRACT

This study examines the effect of the Flipped Classroom learning model on psychomotor learning outcomes (prototype design skills) of Class X Automotive Engineering students at SMK Negeri 1 Sawit Boyolali. This research employed a quasi-experimental method with a nonequivalent control group design. The sample consisted of 71 students: Class X TO 2 (n=35) as the experimental group receiving Flipped Classroom instruction, and Class X TO 4 (n=36) as the control group using Guided Discovery. Data were collected through performance assessment using a rubric covering five aspects of prototype design: tools usage, layout, element selection, innovation, and theme suitability. Data analysis included descriptive statistics, normality and homogeneity tests, Independent Sample t-Test, and Cohen's d effect size. Results indicated that the experimental group achieved a higher average post-test score (78.57) and N-Gain (0.391) compared to the control group (76.81; N-Gain 0.334). However, the Independent Sample t-Test yielded $t = 0.675$ ($p = 0.502 > 0.05$), indicating no statistically significant difference. Cohen's $d = 0.160$ revealed a small effect size. Despite this, descriptive analysis showed that the Flipped Classroom model produced more evenly distributed improvements, with 54.29% of experimental students achieving moderate N-Gain compared to only 30.56% in the control group. This study concludes that although the Flipped Classroom model has not produced statistically significant differences, it demonstrates promising potential in enhancing the quality and equity of psychomotor learning outcomes in vocational education.

Keywords: *Canva, Flipped Classroom, Prototype Design, Psychomotor Learning Outcomes, SMK*



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INTRODUCTION

Vocational education in Indonesia, particularly through Sekolah Menengah Kejuruan (SMK), faces the dual challenge of meeting industry-ready competency standards while integrating 21st-century digital learning approaches. The Revitalization of Vocational Education Policy (Republik Indonesia, 2022) mandates competency-based learning aligned with the world of work, emphasizing practical skills, curriculum alignment, and technology-based learning innovations. Concurrently, the Merdeka Belajar curriculum framework (Kemdikbudristek, 2022) promotes student learning autonomy, digital literacy, and the use of open educational resources as the core of the learning experience.

At SMK Negeri 1 Sawit Boyolali, the Informatics subject serves as a strategic vehicle to develop students' 21st-century competencies, including computational thinking, problem-solving, and proficiency in technology applications. However, classroom observations and preliminary questionnaire data involving 52 students revealed several critical challenges: 62% reported low interest in teacher-centered instruction; 55% felt that material was delivered too fast; and 73% admitted difficulty understanding Informatics concepts without additional practice opportunities. Furthermore, analysis of daily test scores showed that 13 out of 33 students (39%) scored below the Minimum Competency Criterion (KKM = 75), indicating significant inequality in learning outcomes.

These challenges point to a fundamental problem: insufficient class time for hands-on practice due to the time consumed by direct instruction. The Flipped Classroom model (Lage et al., 2000) addresses this by inverting the traditional learning sequence. Students access instructional materials videos, digital modules independently before class (pre-class phase), while in-class time is entirely devoted to practice, discussion, and collaborative problem-solving. This restructuring extends effective practice time within the same instructional hours while enabling the teacher to provide personalized feedback during practice activities.

Previous studies confirm the model's potential. Herlambang & Rachmadi (2024) demonstrated higher procedural and psychomotor outcomes in vocational students under Flipped Classroom. Wang et al. (2022) showed significant psychomotor skill improvements in nursing education. Meta-analyses by Liu (2025) further validated Flipped Classroom's positive impact on motor skill performance. However, most prior research focused on cognitive outcomes or was conducted in general education contexts. The novelty of this study lies in applying Flipped Classroom specifically to psychomotor outcomes in SMK Informatics, targeting prototype design skills using Canva a context combining technical procedural skills with digital creativity under the vocational education framework.

This study therefore aims to examine the effect of the Flipped Classroom learning model on the psychomotor learning outcomes (prototype design skills) of Class X Automotive Engineering students at SMK Negeri 1 Sawit Boyolali, with the hypothesis that Flipped Classroom produces significantly better psychomotor outcomes compared to Guided Discovery.

METHODS

Research Design

This study employed a quasi-experimental method (Campbell & Stanley, 1963) with a Pre--Post-test Nonequivalent Control Group Design, appropriate when random assignment of individuals is not possible in real school settings. Two naturally formed classes served as research samples: Class X TO 2 (n=35) as the experimental group receiving the Flipped Classroom model, and Class X TO 4 (n=36) as the control group continuing with the Guided Discovery model. The research design is presented in Table 1.

Table 1. Quasi-Experimental Research Design

Group	Pre-test	Treatment	Post-test
Experimental	O ₁	X (Flipped Classroom)	O ₂
Control	O ₃	– (Guided Discovery)	O ₄

Participants

The population consisted of all Class X Automotive Engineering (TO) students at SMK Negeri 1 Sawit Boyolali in the 2025/2026 academic year (N=142, across four classes). Sampling used cluster sampling (Sugiyono, 2022; Fraenkel et al., 2019), selecting two classes with comparable prior academic achievement. The experimental group comprised 35 students and the control

group 36 students, totaling 71 participants. Both classes used the same curriculum, teaching schedule, and subject teacher, ensuring baseline equivalence.

Learning Intervention

The Flipped Classroom intervention was implemented across multiple meetings on the topic of Application UI Design Prototype using Canva. In the pre-class phase, students independently accessed teacher-prepared instructional videos, digital modules, and step-by-step tutorial materials at home. In the in-class phase, all classroom time was dedicated to direct practice, discussion, collaborative problem-solving, and individualized teacher feedback. The control group followed the standard Guided Discovery model, where the teacher delivered new material in class before practice activities, following the school's established approach (Bergmann & Sams, 2012; Bishop & Verleger, 2013).

Instrument and Assessment

Learning outcomes were measured using a performance assessment instrument a psychomotor skills rubric administered as both pre-test and post-test. The pre-test required students to create a simple login/front-page design without prior instruction. The post-test required a more complex prototype design applying the learned design principles. The rubric assessed five aspects on a 1-4 scale: (1) Tools Usage, (2) Layout, (3) Element Selection, (4) Innovation/Creativity, and (5) Theme Suitability. Total maximum score was 20, converted to a 0–100 scale. Instrument validity was established through expert judgment (content validity) by an Informatics subject matter expert and an educational evaluation expert. Reliability was confirmed using Cronbach's Alpha ($\alpha > 0.7$), ensuring internal consistency of the rubric (Arikunto, 2019; Creswell, 2018). The rubric was grounded in Dave's (1970) psychomotor taxonomy, targeting development from Level 2 (Manipulation) to Level 3 (Precision).

Data Analysis

Data analysis followed three stages: (1) Descriptive statistics mean, standard deviation, maximum and minimum values, and N-Gain scores using Hake's (1999) formula; (2) Prerequisite tests normality (Shapiro-Wilk, appropriate for $n < 50$) and homogeneity of variance (Levene's Test); (3) Hypothesis testing using Independent Sample t-Test at $\alpha = 0.05$, supplemented by Cohen's d effect size calculation. Student response data were analyzed using percentage descriptive statistics. All analyses were conducted using SPSS.

RESULTS AND DISCUSSION

Results

1. Descriptive Statistics

Table 2. Comparative Descriptive Statistics of Both Groups

Component	Experimental (X TO 2)	Control (X TO 4)
N	35	36
Mean Pre-test	65.43	66.53
Mean Post-test	78.57	76.81
SD Pre-test	8.94	8.93
SD Post-test	10.26	11.72
Mean Gain Score	13.14	10.28
Mean N-Gain	0.391	0.334
N-Gain Category	Moderate	Moderate

The experimental and control groups demonstrated comparable prior ability with pre-test means of 65.43 and 66.53, respectively (difference = 1.10 points). This baseline equivalence is

essential for attributing post-test differences to the learning model rather than prior ability (Creswell, 2012). After the intervention, the experimental group achieved a mean post-test score of 78.57 (gain = 13.14; N-Gain = 0.391, moderate category), while the control group reached 76.81 (gain = 10.28; N-Gain = 0.334, moderate category). Table 2 presents the complete comparative descriptive statistics.

The N-Gain distribution reveals a more pronounced difference between groups. In the experimental group, 54.29% of students achieved moderate N-Gain, compared to only 30.56% in the control group. Conversely, the control group was dominated by low N-Gain (52.78%) versus 31.43% in the experimental group, as detailed in Tables 3 and 4.

Table 3. N-Gain Distribution – Experimental Group (X TO 2)

Category	Criterion	N	%
High	$g \geq 0.70$	5	14.29
Moderate	$0.30 \leq g < 0.70$	19	54.29
Low	$g < 0.30$	11	31.43
Total	–	35	100.00

Table 4. N-Gain Distribution – Control Group (X TO 4)

Category	Criterion	N	%
High	$g \geq 0.70$	6	16.67
Moderate	$0.30 \leq g < 0.70$	11	30.56
Low	$g < 0.30$	19	52.78
Total	–	36	100.00

2. Per-Aspect Rubric Analysis

Analysis of rubric scores per aspect, referenced against Dave's (1970) psychomotor taxonomy levels, reveals that all pre-test scores (range 2.22–2.89) aligned with Level 2 (Manipulation) indicators students could perform tasks following instructions but without independence or consistency. After the intervention, all post-test scores moved to the range 2.61–3.37, indicating achievement of Level 3 (Precision) indicators. Table 5 presents the per-Aspect comparison.

Table 5. Mean Rubric Score per Aspect – Both Groups

Aspects	Experimental			Control		
	Pre	Post	Δ	Pre	Post	Δ
Tools Usage	2.80	3.23	+0.43	2.72	3.11	+0.39
Layout	2.23	2.83	+0.60	2.22	2.61	+0.39
Element Selection	2.80	3.37	+0.57	2.69	3.28	+0.58
Innovation	2.71	3.20	+0.49	2.89	3.22	+0.33
Theme Suitability	2.54	3.09	+0.54	2.78	3.14	+0.36

The layout aspect showed the most notable difference: the experimental group advanced from Level 2 (2.23) to Level 3 (2.83, $\Delta+0.60$), while the control group remained at Level 2 (2.61, $\Delta+0.39$). This is the only aspect where the two groups occupied different psychomotor levels post-intervention the strongest evidence that Flipped Classroom more effectively facilitates the Level 2→Level 3 transition in aspects requiring direct practice and visual concentration. The innovation/creativity aspect also demonstrated a faster progression rate in the experimental group ($\Delta+0.49$ vs. $\Delta+0.33$), reflecting the more conducive environment for creative exploration enabled by independent pre-class learning (Salsabela, 2025; Liu, 2025).

3. Pre-requisite Tests

Shapiro-Wilk normality tests (appropriate for $n < 50$; Field, 2009) confirmed normal distribution for all four datasets (Sig. > 0.05): pre-test control (SW = .960, $p = .236$), post-test control (SW = .943, $p = .068$), pre-test experimental (SW = .951, $p = .124$), post-test experimental (SW = .963, $p = .275$). Levene's Test for equality of variances yielded $F = 1.778$ ($p = .187 > 0.05$), confirming homogeneous variances between groups. These results validated the use of parametric Independent Sample t-Test.

4. Hypothesis Testing

The Independent Sample t-Test with equal variances assumed yielded $t = -0.675$ ($|t| = 0.675$), $df = 69$, $p = 0.502$. Since $|t|$ (0.675) $<$ t -table (1.995) and p (0.502) $>$ α (0.05), H_0 is accepted: there is no statistically significant difference in psychomotor learning outcomes between the Flipped Classroom and Guided Discovery groups at the 95% confidence level. The 95% CI (-6.987 to 3.455) encompasses zero, confirming this result.

Table 6. N-Gain Distribution – Control Group (X TO 4)

Component	Value
Levene's F	1.778
Sig. Levene (homogeneity)	.187
t-value	-0.675
df	69
Sig. (2-tailed) / p-value	.502
Mean Difference	-1.766
Std. Error Difference	2.617
95% CI Lower	-6.987
95% CI Upper	3.455
t-table ($\alpha=0.05$; $df=69$)	1.995

Cohen's $d = 0.160$ indicates a small effect size (Cohen, 1988). Post-hoc power analysis estimated statistical power at approximately 0.20 – 0.25 —well below the recommended threshold of 0.80 (Cohen, 1988). This low power suggests insufficient sample size to detect a small effect ($d \approx 0.2$), estimating a requirement of approximately 250 students per group for adequate detection. These findings are consistent with Hew & Lo (2018), whose meta-analysis found that Flipped Classroom generally produces better outcomes but with varying effect sizes depending on implementation context and sample size.

Table 7. Effect Size (Cohen's d) Calculation

Component	Value
Mean Post-test Experimental	78.57
Mean Post-test Control	76.81
Mean Difference	1.766
Pooled SD	11.06
Cohen's d	0.160
Effect Size Category	Small ($d < 0.2$)

Discussion

The absence of statistically significant differences does not negate the practical potential of Flipped Classroom. Three contextual factors require consideration. First, the limited intervention duration (one teaching unit) was insufficient for students to fully adapt to the independent pre-class learning pattern. Flipped Learning Network (2014) emphasizes that effectiveness is contingent on students consistently completing pre-class materials a habit requiring sustained practice. Second, the small sample size ($n = 35$ and 36) produced inadequate

statistical power, limiting the test's ability to detect small but real effects. Third, unmeasured mediating variables pre-class video access frequency, self-directed motivation, and device availability outside school may have moderated the effect.

Despite statistical non-significance, the descriptive advantage of Flipped Classroom is consistent across all measured indicators: higher mean post-test, larger gain score, higher N-Gain, and most importantly more equitable distribution of learning improvement. The shift of 54.29% of experimental students to moderate N-Gain versus 30.56% in control, and the reduction of students with low N-Gain (31.43% vs. 52.78%), reflects the mechanism described by Bergmann & Sams (2012): pre-class exposure enables students to arrive at practice sessions with prior understanding, maximizing direct practice time and enabling more personal teacher feedback. This addresses two of the three root problems identified in the preliminary study insufficient practice time and unequal learning outcomes (Bishop & Verleger, 2013).

The layout aspect's unique finding the experimental group achieving Level 3 (Precision) while the control group remained at Level 2 (Manipulation) provides concrete empirical support for the cognitive load reduction mechanism. By separating conceptual acquisition (pre-class) from skill application (in-class), Flipped Classroom allows students to dedicate full working memory capacity to the visual concentration and trial-and-error required for layout refinement (Piaget, 1972; Fosnot, 2013). This finding is particularly relevant for vocational education, where psychomotor skill development progressing through Dave's (1970) taxonomy from Imitation through Articulation requires repeated practice with immediate corrective feedback.

From a broader vocational education policy perspective, these findings align with the Merdeka Belajar framework's (Kemdikbudristek, 2022) emphasis on learning independence, digital literacy, and student-centered pedagogies. The Flipped Classroom model structurally operationalizes these principles, making it a contextually appropriate and theoretically sound innovation for SMK.

CONCLUSION

This study concluded that the Flipped Classroom learning model did not produce statistically significant differences in psychomotor learning outcomes in prototype design compared to the Guided Discovery model among 10th-grade Automotive Engineering students at SMK Negeri 1 Sawit, Boyolali. However, descriptive analysis consistently favored the Flipped Classroom: the experimental group achieved higher average post-test scores, greater gain scores, higher N-Gain, and a more even distribution of gains among experimental students in the medium N-Gain category compared to the control group. The statistically insignificant results were due to the limited duration of the intervention, the small sample size resulting in insufficient statistical power, and the students' adaptation phase to self-paced pre-class learning.

These findings suggest that the Flipped Classroom has promising potential to improve the quality and equity of psychomotor learning in vocational education, particularly when implemented over a full semester with a larger sample size and a gradual introduction of students to self-paced pre-class learning. Future research should utilize a larger sample size, a longer intervention period, and measurement of mediating variables such as frequency of pre-class video access, intrinsic motivation, and out-of-school digital access.

CONFLICT OF INTEREST

The authors declare no conflict of interest in the preparation and publication of this research article.

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Descriptive Analysis of the Edutainment Program *For Your Pagi* on Trans7 in Improving Teenager Digital Literacy

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ABSTRACT

This study aims to describe and analyze the strategic utilization of the *For Your Pagi* (FYP) edutainment program on Trans7 in improving teenager digital literacy. Employing a qualitative approach with a qualitative descriptive design, this research gathered data through a purposive sampling technique involving four primary informants: two internal media practitioners (the producer and creative team member of Trans7) and two external informants (teenagers aged 17–20). Data collection techniques were rigorously executed via semi-structured interviews, participatory observation during the researcher's embedded internship, and documentation studies of broadcasting scripts and actual televised episodes. Data validity was ensured through source and technique triangulation, and analysis was systematically performed using the interactive model of Miles, Huberman, and Saldaña. The findings reveal that the FYP program effectively deploys educational message design strategies within a non-formal broadcasting environment by systematically integrating John Keller's ARCS Motivation Model (Attention, Relevance, Confidence, Satisfaction). This structural edutainment balance exhibits a verifiable impact on accelerating the digital literacy competencies of teenagers based on the four pillars of Paul Gilster's Theory. However, a significant operational constraint persists.

Keywords: ARCS Model, Digital Literacy, Edutainment, Learning Resources, Teenagers



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INTRODUCTION

The massive, continuous, and unprecedented advancement of digital information technologies in the modern era has pushed contemporary society into a state of structural information deluge. The democratization of internet connectivity across various societal strata opens vast, borderless pathways for knowledge acquisition; however, the unregulated and hyper-accelerated nature of these digital media landscapes simultaneously triggers a widespread disinfodemic pattern. Modern digital channels frequently act as echo chambers that catalyze the rapid proliferation of systemic disinformations, misinformations, and malicious fake news (hoaxes). This informational vulnerability is particularly pronounced among the younger demographic, specifically teenagers, who exhibit intense daily screen-time metrics but often lack the necessary cognitive infrastructure to critically evaluate incoming stimuli.

Confronted with this perilous digital ecosystem, national broadcasting institutions carry a vital, legally mandated responsibility according to Indonesian Law No. 32 of 2002 to actively

manifest an educational function for the public. While internet-based alternative media continue to proliferate, empirical metrics demonstrate that conventional media forms have not lost their structural authority. Data from national viewership surveys indicates that television penetration across Indonesian households remains exceptionally high at approximately 81%, and remarkably, television continues to be deemed the most trusted and reliable information source (43.1%) by the general public when contrasted against the volatility, anonymity, and algorithmic bias of social media platforms (Indonesia, 2023; Pahlevi, 2022). This reality positions television as a critical cultural gatekeeper capable of shaping public consciousness and distributing standardized knowledge to mass audiences simultaneously (Kuswandi, 1996; Shoemaker & Vos, 2009).

Despite this profound structural reach, a distinct and critical empirical gap emerges within the educational and media landscape of Indonesia. There is a severe, documented discrepancy between the urgent, immediate societal need for media verification competencies and the absolute scarcity of informal educational channels capable of reaching a massive audience base seamlessly without inducing cognitive fatigue (Fitriyani & Teguh Nugroho, 2022; Lestari & Dwijayanti, 2020). Traditional, formal educational institutions often struggle to keep pace with the real-time evolution of cyber-threats due to rigid curricular frameworks (Akbar & Noviani, 2019; Surani, 2019). Therefore, a strategic shift toward public pedagogy is required, where educational technology principles are applied outside classroom walls to capture learners in their natural media-consumption environments (Sandlin et al., 2011).

From the established conceptual paradigm of Educational Technology, as formally articulated by the Association for Educational Communications and Technology, television media should not merely serve as a tool for passive, low-cognition recreation (AECT, 2004; Januszewski & Molenda, 2008). Instead, television can be purposefully repositioned and intentionally designed as a "learning resource by utilization" (learning resources by utilization) within the broader non-formal education ecosystem (Coombs & Ahmed, 1974; Handayani, 2023). When media is transformed into an intentional learning asset, it bridges the gap between entertainment seeking and knowledge acquisition (Arsyad, 2013; Rusman, 2012).

The morning television program *For Your Pagi* on Trans7 emerged as a strategic edutainment intervention attempting to bridge this empirical gap by packaging the clarification of highly volatile, viral internet issues through a lightweight talkshow format. Nevertheless, a persistent paradoxical phenomenon dominates contemporary commercial broadcasting: morning variety shows and terrestrial morning talkshows frequently suffer from severe pedagogical degradation, systematically diluting their educational value to chase immediate commercial revenue, shallow sensationalism, and superficial gimmicks (Amalia et al., 2022; Saptya et al., 2019).

The core urgency of this study lies in analyzing how *For Your Pagi* operates as a deliberate anomaly within this commercial landscape, positioning critical digital literacy as its core content (core content) amidst intense industrial rating pressures. While previous media literacy studies focus extensively on formal classroom media or dry public service announcements, there is a distinct lack of empirical investigation into how commercial variety television utilizes systematic instructional design to cultivate media literacy among the youth (Judijanto, 2024; Komalasari & Saripudin, 2018). Therefore, this study aims to describe and analyze deeply the strategic utilization of the edutainment program *For Your Pagi* on Trans7 in enhancing teenager digital literacy.

METHODS

This study adopted a qualitative approach utilizing a qualitative descriptive design. This methodology was specifically selected to construct a systematic, factual, and highly accurate description regarding the execution of educational message design and its corresponding

cognitive reception by the target audience without manipulating the natural research setting (Sugiyono, 2019). The research operations were centered within the production studio and broadcasting headquarters of Trans7 in South Jakarta, spanning a six-month intensive field execution period from January to June 2026.

1. Informants and Sampling Technique

The research subjects and key informants in this study were determined using a strict purposive sampling technique to guarantee that the selected individuals possessed deep, direct, and unmediated exposure to the phenomenon, yielding a total of four primary informants. The sample was balanced between internal production agents who design the message and external consumers who process it:

- a. Internal Informants: The Executive Producer of the *For Your Pagi* program (referred to as BH, aged 34) and a senior member of the Creative Production Team (referred to as RN).
- b. External Informants: Two active teenage viewers who regularly consume the program and fall directly into the critical demographic range of 17 to 20 years old, designated as YA (20 years old) and MR (20 years old).

2. Data Collection and Instrument Alignment

Data collection was comprehensively carried out using three cross-verifiable techniques to minimize subjective reporting bias:

- a. Semi-Structured Interviews: Conducted via an interview guide that directly synthesizes the motivational indicators of John Keller's ARCS model (Attention, Relevance, Confidence, Satisfaction) with the operational dimensions of Paul Gilster's digital literacy theory.
- b. Participatory Observation: Executed firsthand by the researcher during an extended, immersive internship period inside the *For Your Pagi* production unit, allowing direct mapping of live script adjustments, control booth operations, and producer decisions during live airtime.
- c. Documentation Studies: A systematic analysis conducted on live broadcast scripts, internal production run-sheets, visual telemetry data, and final televised master control tapes.

3. Data Validity and Analysis

To ensure robust qualitative validity and reliability, the gathered data was subjected to two distinct triangulation strategies: source triangulation (cross-examining data obtained from the internal television producers against the raw experiential accounts of the teenage viewers) and technique triangulation (validating interview testimonies against direct observation logs and internal script documents).

The data was analyzed using the interactive qualitative model proposed by Miles, Huberman, and Saldaña. This analysis proceeded through a continuous, triple-tracked stream: data condensation (filtering, focusing, abstracting, and compressing verbatim interview transcripts and field notes), data display (structuring information systematically through thematic coding matrices), and conclusion drawing or verification.

RESULTS AND DISCUSSION

Results

The field findings indicate that the Trans7 production team actively designs its messaging to pull in attention by modifying scripts and treating viral social media trends as an initial "hook" or bait in the opening segment. Once the viewer's attention is locked, the production team diverts the talkshow's trajectory toward digital safety and media verification education. To

optimize comprehension, the creative team intentionally simplifies complex, technical terminology into concise, actionable points paired with dynamic on-screen graphics.

However, a recurring operational friction occurs during live broadcasts: a constant tension between keeping viewers hooked and meeting commercial rating targets. This commercial pressure frequently causes the hosts' comedic improvisation to overshadow the educational content, trimming the time allocated for expert guests. On the receiving end, teenage viewers show higher engagement when the topics directly match their daily lives or hobbies, such as cyber-fraud warnings or rescue updates from search and rescue personnel.

Furthermore, a significant shift in media consumption habits was observed; teenagers show a strong preference for watching recorded segments on-demand via YouTube over live television broadcasts. Technique triangulation confirmed clear consistency between the original production scripts and the final visual elements, such as pop-up graphics and "Red Dot" indicators, which aligned well with the audience's understanding.

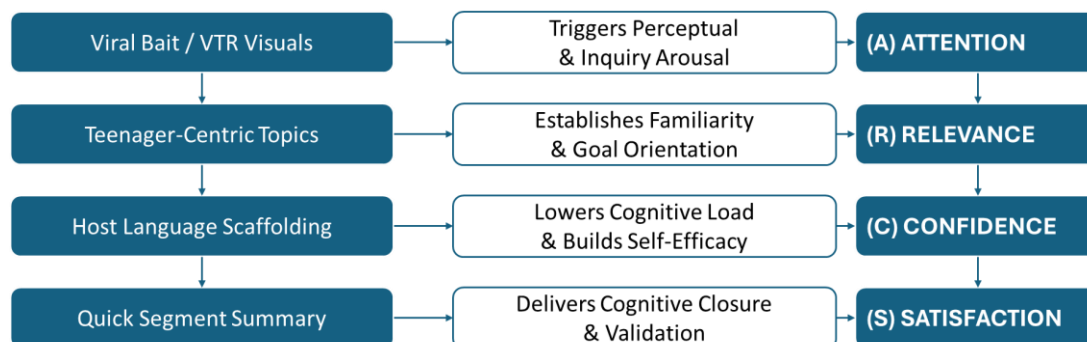
The condensed qualitative data illustrating these thematic codes is structured in the matrix below:

Table 1. Data condensation results

Theme (Category)	Code Findings	Verbatim Interview Excerpt	Informant Source
Edutainment Strategy	A1. Use of Viral "Bait" (Attention)	<i>"Our strategy uses a 'bait' system... in the initial segment, I lure them using a celebrity topic that is currently buzzing... only then do we steer the discussion toward digital education..."</i>	B.H (Producer, 34)
	A2. Script and Visual Simplification	<i>"...I strictly avoid writing scripts using complicated language... we break it down into brief points... playing it up through studio screen visuals (VTR) and sound effects..."</i>	R.N (Creative Team)
Message Relevance	B1. Closeness of Issue to Teenager Concerns	<i>"...honestly, that Rinjani case was already viral on social media... so seeing detailed information directly from the search and rescue (SAR) team was great... because my hobby is mountain climbing..."</i>	Y.A (Teenager, 20)
	B2. Dismissal of Irrelevant Content	<i>"It depends on the issue, bro. If it doesn't feel important or relevant to me, I just skip it..."</i>	M.R (Teenager, 20)
Literacy Impact	C1. Content Evaluation	<i>"...it has made me much more critical. Sometimes, if I find information on social media that I've never seen before, I crosscheck it on TV, and vice versa..."</i>	M.R (Teenager, 20)
	C2. Basic Awareness	<i>"...at that time, I immediately went to search for further updates... just to make sure I wouldn't fall for the hoax."</i>	Y.A (Teenager, 20)
Practical Barriers	D1. Runtime Cut by Comedy	<i>"...but sometimes, the educational element loses out to the comedy aspect... because the hosts get too carried away with improvisation..."</i>	B.H (Producer, 34)
	D2. Pressures of the Rating Curve	<i>"The ultimate challenge is the tug-of-war over audience attention. If the educational content gets too technical... the rating graph... will instantly drop..."</i>	B.H (Producer, 34)

To systematically conceptualize how the production strategies, script modifications, and host delivery style intertwine to systematically engage the audience, the empirical findings of the program's transmission flow are mapped out into a structured flowchart below (see Figure 1).

Figure 1. The Structural Integration of the ARCS Motivational Model within *For Your Pagi*



Discussion

The integration of John Keller's ARCS Motivation Model within *For Your Pagi's* broadcast structure shows a deliberate alignment with instructional design principles. The Attention component is achieved through perceptual arousal—using interactive graphics and studio pacing—and inquiry arousal, driven by framing viral social media issues as an educational starting point. This matches standard edutainment theories where media must first break through digital fatigue to establish cognitive engagement (Colace et al., 2006; Ziep, 2014).

Relevance is built by aligning topics with issues teenagers care about, creating familiarity, and offering functional solutions to cyber threats (goal orientation). This dynamic supports public pedagogy frameworks which state that informal media gains educational value when viewers see the content as useful for navigating their daily lives (Nur'Aini, 2022; Sandlin et al., 2011).

Confidence is supported by the hosts' casual language, which acts as an instructional scaffolding mechanism that simplifies technical concepts. By translating jargon into accessible ideas, the program lowers cognitive barriers, helping teenage viewers feel capable of understanding digital security. This outcome demonstrates Bandura's (1986) social cognitive theory, where relatable modeling strengthens self-efficacy and encourages observational learning.

Finally, Satisfaction is reinforced through brief summary segments at the end of each topic, providing clear takeaways that solidify understanding. This deliberate structure aligns with standard instructional design models like ADDIE, which emphasize providing clear conclusions to secure learning outcomes (Pribadi, 2011). Furthermore, the unique host-viewer dynamic builds a form of para-social interaction, making the educational advice feel like a trusted recommendation from a peer rather than an institutional lecture (Horton & Wohl, 1956).

The study shows that balancing these edutainment strategies relates closely to improvements across the four pillars of digital literacy from Paul Gilster's Theory:

1. Internet Searching: The program's viral hooks serve as a starting point that encourages teenage viewers to look up information independently.
2. Hypertextual Navigation: Focusing on trending social media topics encourages users to follow and verify information across multiple platforms, transforming their viewing habits (UNESCO, 2018).
3. Content Evaluation: Simplifying technical jargon helps teenagers build the critical thinking skills needed to spot, cross-check, and filter out hoaxes.
4. Knowledge Assembly: The segment summaries help viewers organize scattered pieces of information into a coherent understanding of digital safety.

These findings show that under the right conditions, television can shift teenage viewers from passive media consumers into active literacy participants within their peer groups. However, the main challenge remains commercial: the constant pressure to maintain high television ratings can cause entertainment elements to cut into the time needed for educational content. This tension underlines a broader issue in educational technology regarding commercial broadcasting: pedagogical goals must constantly compete with market demands (Akbar & Noviani, 2019; Febriansyah, 2023).

CONCLUSION

The program *For Your Pagi* (FYP) on Trans7 shows how non-formal broadcasting media can deliver educational content by organizing its messaging around the ARCS Motivation Model. Despite facing structural challenges, such as host comedy cut-ins and commercial rating demands, the program has a measurable positive impact on developing digital literacy skills among teenagers across Gilster's four pillars. The program's approach successfully encourages independent online research, improves cross-platform navigation, builds critical skills to counter misinformation, and helps viewers assemble a clearer understanding of digital issues.

Based on these conclusions, it is recommended for production teams should establish stricter runtime management for live ad-libbing and comedic sketches. This ensures that the educational core of edutainment programs is preserved and expert commentary is not cut short by entertainment elements. Also, for future researchers, it is recommended to expand on these qualitative insights by conducting quantitative experimental studies. Future work should measure the empirical shift in media literacy scores across larger, demographically diverse teenage populations to test the scalability of this edutainment format.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript.

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The Relationship Between Tiktok Media Usage and Digital Literacy with Students' Participation in Learning at SMKN 2 Karanganyar

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ABSTRACT

This study aimed to: (1) determine the relationship between TikTok usage and students' participation in learning, (2) determine the relationship between digital literacy and students' participation in learning, and (3) examine the simultaneous relationship between TikTok usage and digital literacy with students' participation in learning at SMKN 2 Karanganyar. This research was motivated by the low level of student participation in classroom learning and the high intensity of TikTok usage among students, which potentially influences their learning engagement. The study employed a quantitative approach with an ex post facto correlational design. The population consisted of 432 tenth-grade students of SMKN 2 Karanganyar, with 191 students selected as the sample using cluster sampling techniques. Data were collected through questionnaires and documentation. The research instruments included questionnaires on TikTok usage, digital literacy, and student participation in learning based on the theories of participatory culture, UNESCO Digital Literacy Global Framework, and student engagement. Data analysis used multiple linear regression to examine partial and simultaneous relationships among variables. The results showed that: (1) there was a positive and significant relationship between TikTok usage and students' participation in learning, (2) there was a positive and significant relationship between digital literacy and students' participation in learning, and (3) there was a positive and significant simultaneous relationship between TikTok usage and digital literacy with students' participation in learning. The findings indicate that educationally oriented TikTok usage supported by adequate digital literacy skills can enhance students' behavioral, emotional, and cognitive engagement in the learning process. Therefore, schools and teachers are encouraged to utilize social media more pedagogically and strengthen students' digital literacy to support optimal learning participation.

Keywords: *digital learning media, digital literacy, TikTok, , student participation, student engagement,*



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INTRODUCTION

The development of 21st-century education requires students to possess critical thinking, creativity, communication, and collaboration skills in order to adapt to rapid technological and social changes. In this context, the role of teachers has shifted from merely delivering information to facilitating active and student-centered learning experiences. Therefore, learning participation becomes an essential aspect in achieving meaningful learning outcomes, particularly in vocational education, where students are expected to develop both technical competencies and soft skills through active engagement in learning activities.

Student participation in learning is closely related to the concept of student engagement, which includes behavioral, emotional, and cognitive involvement during the learning process. Active participation enables students to interact, collaborate, ask questions, and engage deeply with learning materials. However, preliminary observations conducted during teaching practice at SMKN 2 Karanganyar indicated that student participation in classroom learning was still relatively low. Many students tended to be passive during discussions, showed limited initiative in asking questions, and often lost focus during instructional activities. This condition potentially hinders the development of vocational competencies that require active and contextual learning experiences.

At the same time, today's students grow up within a digital environment where social media platforms have become part of their daily lives. One of the most popular platforms among adolescents is TikTok, which provides short-form video content that is visual, interactive, and easily accessible. Indonesia itself has become one of the countries with the largest number of TikTok users in the world, dominated by young users. The popularity of TikTok among students indicates that digital media significantly shapes their communication patterns, information consumption, and learning preferences.

The characteristics of TikTok align with the concept of microlearning and multimedia learning theory, where information is delivered through concise audiovisual content that can improve students' attention and understanding. Several studies have shown that TikTok can support learning activities by increasing students' motivation, interest, and engagement through creative and contextual content delivery. TikTok also allows students to participate actively by responding to, creating, and sharing educational content. Consequently, TikTok has the potential to function not only as entertainment media but also as an educational medium that supports learning participation.

Nevertheless, the impact of TikTok on students' learning participation cannot be separated from students' digital literacy abilities. Digital literacy refers to the ability to access, evaluate, manage, create, and communicate information effectively through digital technologies. Students with good digital literacy are more likely to utilize TikTok productively for educational purposes, while those with lower digital literacy may use the platform primarily for entertainment and distraction. Therefore, digital literacy becomes an important factor influencing how students interact with digital media in educational contexts.

Previous studies have examined the role of TikTok in enhancing learning engagement and the influence of digital literacy on students' learning behavior. However, most studies still investigate these variables separately. Research that simultaneously analyzes the relationship between TikTok usage, digital literacy, and student participation in vocational education contexts remains limited. This gap highlights the importance of conducting further empirical investigation, particularly in Indonesian vocational high schools.

Based on these conditions, this study aims to analyze: (1) the relationship between TikTok usage and students' participation in learning, (2) the relationship between digital literacy and students' participation in learning, and (3) the simultaneous relationship between TikTok usage and digital literacy with students' participation in learning at SMKN 2 Karanganyar. The findings of this study are expected to contribute to the development of digital-based learning strategies and provide practical recommendations for integrating social media into educational practices more effectively and pedagogically.

METHODS

Research Design

This study employed a quantitative approach using an ex post facto correlational research design. Quantitative research is used to examine relationships among variables through numerical data and statistical analysis (Creswell, 2018). The ex post facto approach was selected

because the study investigated existing phenomena without manipulating the independent variables. Meanwhile, the correlational design aimed to identify the relationship between TikTok usage, digital literacy, and students' participation in learning.

The research was conducted at SMKN 2 Karanganyar, Indonesia. The population consisted of all tenth-grade students totaling 432 students. The sample was determined using the Isaac and Michael sampling table with a 5% significance level, resulting in 191 respondents. The sampling technique used was cluster sampling because the population was naturally grouped into several classes and study programs.

Research Procedure and Data Analysis

The research procedure was carried out through several stages. The first stage involved preliminary observation and problem identification during teaching practice activities at SMKN 2 Karanganyar. The observations revealed that students' participation in classroom learning was still relatively low, while the use of TikTok among students was highly intensive. Based on these findings, the researcher formulated the research problems and developed the conceptual framework.

The second stage involved instrument development based on the theoretical framework of participatory culture, UNESCO Digital Literacy Global Framework, and student engagement theory proposed by Fredricks et al. (2019). Three questionnaires were developed to measure TikTok usage, digital literacy, and students' participation in learning. The instruments used a Likert scale and were validated through expert judgment before being tested empirically.

The third stage consisted of instrument testing to determine validity and reliability. Instrument validity was analyzed using Pearson Product Moment correlation, while reliability testing employed Cronbach's Alpha coefficient. The validity and reliability tests were conducted on students outside the research sample to ensure the quality and consistency of the instruments.

The fourth stage was data collection, which was conducted through questionnaire distribution and documentation techniques. The questionnaires were administered directly to the respondents to obtain data regarding students' TikTok usage, digital literacy level, and participation in learning activities.

The collected data were analyzed using descriptive and inferential statistical techniques. Descriptive statistics were used to describe the characteristics of each variable, including mean, percentage, and distribution of responses. Prior to hypothesis testing, prerequisite analyses were conducted, including normality, linearity, and multicollinearity tests to ensure that the data met regression assumptions.

Hypothesis testing employed multiple linear regression analysis to examine both partial and simultaneous relationships among variables. The t-test was used to analyze the partial relationship between each independent variable and the dependent variable, while the F-test was used to determine the simultaneous relationship between TikTok usage and digital literacy with students' participation in learning. Statistical analysis was conducted using SPSS software with a significance level of 0.05.

RESULTS AND DISCUSSION

Results

This study involved 191 tenth-grade students of SMKN 2 Karanganyar as research respondents. The collected data were analyzed using descriptive and inferential statistical techniques to examine the relationship between TikTok usage, digital literacy, and students' participation in learning.

The descriptive findings indicated that TikTok has become one of the most frequently used digital platforms among students. Approximately 98.4% of respondents reported actively using

TikTok in their daily activities. Most students accessed TikTok for entertainment, information seeking, communication, and viewing short-form audiovisual content. In addition, students demonstrated moderate to high levels of digital literacy and learning participation.

Before hypothesis testing, prerequisite analyses were conducted to ensure that the data fulfilled regression assumptions. The multicollinearity test showed tolerance values of 0.889 and VIF values of 1.125 for both independent variables, indicating that the regression model did not experience multicollinearity. Furthermore, the heteroscedasticity test produced significance values greater than 0.05, confirming that the residual variance was homogeneous.

Table 1. Multicollinearity Test Results

Variable	Tolerance	VIF	Interpretation
TikTok Usage	0.889	1.125	No multicollinearity
Digital Literacy	0.889	1.125	No multicollinearity

Source: Processed research data using SPSS 27 (2026)

Table 2. Heteroscedasticity Test Results

Variable	Sig. Value	Criterion	Interpretation
TikTok Usage	0.206	> 0.05	No heteroscedasticity
Digital Literacy	0.748	> 0.05	No heteroscedasticity

Source: Processed research data using SPSS 27 (2026)

The first hypothesis testing revealed that TikTok usage had a positive and significant relationship with students' participation in learning. The regression coefficient value was 0.568 with a t-value of 8.815 and a significance value of <0.001. These results indicate that students who utilized TikTok more actively and productively tended to demonstrate higher participation during learning activities.

Table 3. Regression Analysis Results of TikTok Usage on Students' Participation

Variable	Regression Coefficient	t-value	Sig.	Interpretation
TikTok Usage	0.568	8.815	<0.001	Significant positive relationship

Source: Processed research data using SPSS 27 (2026)

The second hypothesis testing showed that digital literacy also had a positive and significant relationship with students' participation in learning. The analysis produced a regression coefficient of 0.229, a t-value of 3.335, and a significance value of 0.001. These findings suggest that students with better digital literacy skills were more capable of engaging actively in digital-based learning environments.

Table 4. Regression Analysis Results of Digital Literacy on Students' Participation

Variable	Regression Coefficient	t-value	Sig.	Interpretation
Digital Literacy	0.229	3.335	0.001	Significant positive relationship

Source: Processed research data using SPSS 27 (2026)

The simultaneous regression analysis further demonstrated that TikTok usage and digital literacy collectively had a significant relationship with students' participation in learning. The analysis produced an F-value of 60.991 with a significance value of <0.001. In addition, the coefficient of determination (R^2) was 0.401, indicating that TikTok usage and digital literacy contributed 40.1% to students' participation in learning, while the remaining 59.9% was influenced by other external factors.

Table 5. Simultaneous Regression Analysis Results

Variable	F-value	Sig.	R ²	Interpretation
TikTok Usage & Digital Literacy → Students' Participation	60.991	<0.001	0.401	Significant simultaneous relationship

Source: Processed research data using SPSS 27 (2026)

Discussion

The findings of this study indicate that TikTok usage has a positive and significant relationship with students' participation in learning. The significance value of <0.001 confirms that TikTok contributes substantially to students' engagement during learning activities. TikTok's short-video format, audiovisual presentation, and interactive features appear to support students' behavioral and emotional engagement by increasing attention, interest, and participation in classroom discussions and assignments.

These findings are consistent with previous studies reporting that TikTok can function as an effective digital learning medium because its content characteristics align with students' digital habits and learning preferences. The integration of TikTok into learning activities encourages students to become more active, collaborative, and responsive during the instructional process.

The study also found that digital literacy significantly influences students' participation in learning. Students with strong digital literacy skills are better able to access, evaluate, and utilize digital information critically and responsibly. As indicated by the significance value of 0.001, digital literacy contributes positively to students' ability to engage in technology-supported learning environments. This finding supports previous research emphasizing that digital literacy is an essential competency for meaningful participation in 21st-century learning.

Furthermore, the simultaneous regression analysis demonstrated that TikTok usage and digital literacy together significantly influence students' participation in learning. The coefficient of determination ($R^2 = 0.401$) indicates that both variables explain 40.1% of the variance in students' learning participation. This finding suggests that educationally oriented social media usage supported by adequate digital literacy skills can improve students' behavioral, emotional, and cognitive engagement.

From an educational perspective, the findings imply that schools and teachers should integrate digital media into learning activities more strategically and pedagogically. TikTok can be utilized not only as entertainment media but also as a learning platform that supports interactive and contextual learning experiences. However, the effective use of digital media in education requires strengthening students' digital literacy competencies to ensure responsible and productive technology use.

Overall, this study contributes empirical evidence regarding the relationship between social media usage, digital literacy, and student engagement in vocational education contexts. The findings highlight the importance of aligning educational practices with students' digital culture to create more meaningful and participatory learning environments.

CONCLUSION

This study concludes that TikTok usage and digital literacy have positive and significant relationships with students' participation in learning at SMKN 2 Karanganyar. The results demonstrate that students who utilize TikTok more actively and educationally tend to show higher behavioral, emotional, and cognitive engagement during the learning process. In addition, students with better digital literacy skills are more capable of accessing, evaluating, and utilizing digital information productively, which contributes to stronger participation in technology-supported learning environments.

The simultaneous analysis further confirms that TikTok usage and digital literacy collectively contribute significantly to students' participation in learning, with a contribution value of 40.1%.

These findings indicate that digital learning participation is not only influenced by the availability of attractive digital media but also by students' competencies in using technology critically and responsibly. Therefore, the expectations presented in the introduction regarding the role of digital media and digital literacy in supporting student engagement were empirically confirmed through the results of this study.

The findings provide important implications for educational practices in the digital era, particularly in vocational education contexts. Social media platforms such as TikTok can be integrated into learning activities as interactive and contextual learning media that align with students' digital culture. However, the effectiveness of digital media integration depends on strengthening students' digital literacy competencies to ensure that technology is utilized productively and pedagogically.

Furthermore, this study opens opportunities for future research regarding the implementation of TikTok-based learning strategies in experimental or classroom action research designs to examine their direct effects on learning outcomes, motivation, and engagement. Future studies are also recommended to explore additional variables influencing students' participation in digital learning environments, such as learning motivation, self-regulated learning, teacher support, and digital learning readiness.

CONFLICT OF INTEREST

The author declares no potential conflict of interest related to the research, authorship, and publication of this article.

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Digital Learning in Vocational High Schools Practices: Insights from Teachers' Experiences

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ABSTRACT

The swift advancement of digital technology and Industry 4.0 has heightened the significance of digital learning in vocational education, necessitating the integration of technology into the teaching and learning process inside schools. This study seeks to examine instructors' experiences in the deployment of digital learning and to determine the elements that facilitate and obstruct its execution. A qualitative case study was performed in a vocational high school, involving four teachers and two administrative and infrastructure personnel recruited via purposive sampling. Data were gathered via semi-structured interviews and observations, thereafter processed by theme analysis. Results demonstrate that digital learning is integrated across planning, instruction, and evaluation methodologies. Educators utilize several digital platforms and tools, including accessibility, user-friendliness, and pedagogical suitability. Despite the school's generally sufficient infrastructure, deficiencies in internet connectivity, device availability, and facility use persist as issues. Educators tackle these challenges using adaptive methods such as customized instruction, gamification, peer-assisted learning, and the incorporation of AI literacy. The study indicates that the effective application of digital learning relies on the interplay among teacher practices, digital resources, infrastructural support, and teacher adaptability, hence enhancing the contextual comprehension of the digital learning ecosystem in vocational education.

Keywords: *Digital learning, AI-literacy, Vocational School, Teacher, Perspective.*



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INTRODUCTION

Digital revolution is fundamentally altering education and work, influencing learning methodologies and requisite skills. Emerging technologies and Industry 4.0 have revolutionized company models, labor markets, and skill requirements, rendering digital literacy and competencies vital for employability and competitiveness. Educational institutions face pressure to modernize curricula, include digital tools, and equip learners for a knowledge-based, technology-driven economy (Dahalan et al., 2023)(Tan et al., 2024). Digital learning through platforms, simulations, MOOCs, and various technologies can improve flexibility, engagement, and learning results when integrated with effective pedagogy (Rêgo et al., 2023)(X. Zhang et al., 2024). This necessitates the ongoing enhancement of teachers' digital competencies, alongside

supportive leadership and institutional measures (Alenezi, 2023) (Ali et al., 2024). Digitalization is essential in Vocational Education and Training (VET) due to the strong connection between vocational programs and the swiftly evolving workplaces and industrial technology (Dahalan et al., 2023) (Sánchez-Prieto et al., 2021). Digital learning environments, encompassing e-learning platforms, simulations, gamification systems, and blended learning, facilitate the acquisition of 21st-century skills, including critical thinking, collaboration, and computational thinking, alongside job-specific competencies such as digital marketing (Noguera et al., 2024) (Savka et al., 2025). Studies indicate that the judicious integration of digital and online technologies can enhance academic performance, motivation, learning engagement, and satisfaction (Rêgo et al., 2023) (Savka et al., 2025). Simultaneously, numerous vocational education and training (VET) instructors and learners exhibit disparate digital competencies, and digital technologies remain inadequately incorporated into routine pedagogical practices (Dahalan et al., 2023) (Ali et al., 2024) (Hermans et al., 2024). This establishes a robust framework to assess and enhance digital learning competencies in students, with digital teaching and innovative leadership skills in staff, to provide high-quality and industry-relevant vocational education in the digital era.

The execution of digital learning is contingent upon teachers' classroom practices, the technologies they utilize, and the assistance they receive. Studies indicate that when educators possess positive dispositions, sufficient digital competencies, and substantial professional development, they create more interactive and student-centered lessons utilizing platforms, multimedia, and virtual reality or game-based tools to improve engagement and assessment (Akram et al., 2022) (Lomos et al., 2023). Effective pedagogical practices encompass customizing activities to align with learner attributes, employing problem-centered tasks, utilizing online assessments, implementing learning management systems (e.g., Google Classroom, Moodle), and leveraging digital simulations to elucidate intricate concepts and deliver prompt feedback (Nguyễn et al., 2022) (Lomos et al., 2023). Nonetheless, restricted digital proficiency, absence of training, and adverse or ambiguous attitudes of online education might hinder these activities, particularly when educators possess minimal prior experience with technology.

School infrastructure and organization are equally vital. The frequency and quality of teachers' use of digital platforms and resources are substantially influenced by the availability of stable, high-speed internet, adequate devices, up-to-date software, and technical support (Mintasih et al., 2024) (Woltran et al., 2022). Studies from Thailand and elsewhere show that a successful digital learning ecosystem relies on technology that supports learning, quality digital content, and a supportive learning environment. But these must be underpinned by clear policies, leadership vision, and adequate budgets for infrastructure and teacher development (Cirneanu & Moldoveanu, 2024) (Bitar & Davidovich, 2024)). The "relationship" between teachers, technology, and facilities is two-way: quality infrastructure and curated digital materials make for innovative pedagogy, but teachers' beliefs, expertise, and collaborative practices determine whether the available tools are truly integrated into everyday teaching (Stringer et al., 2022) (Kaimara et al., 2021). Overall success depends on teacher competencies and attitudes, robust infrastructure, institutional vision, and supportive policies. Barriers include lack of resources, unequal access and poor training.

The implementation of digital learning in education contexts has been widely studied in the literature, highlighting its potential to enhance learning flexibility, student engagement, and academic performance through the use of digital platforms, multimedia resources, simulations, and learning management systems (Rêgo et al., 2023) (Noguera et al., 2024). Further research has shown several benefits and problems of technology integration including the importance of teacher digital competency, professional development and institutional support in facilitating effective digital learning practices (Akram et al., 2022) (Alenezi, 2023). However, many of these

studies are mostly based on surveys to measure views, preparedness or acceptance of technology and so provide limited insights into the lived experiences and daily practices of teachers in adopting digital learning. Existing studies have highlighted the vital significance of digital technology in vocational education to prepare students for fast-changing industrial contexts, and to improve digital competence and job-specific competencies (Dahalan et al., 2023)(Wu & Zhong, 2025). Previous studies have addressed topics such as digital competences of students, learning outcomes, technology adoption and workforce preparedness in the context of vocational education (Wu & Zhong, 2025)(Rauseo et al., 2023). Nevertheless, little attention has been made to comprehend vocational teachers' experience of using digital learning in their daily teaching practices, especially with the availability of digital learning resources and institutional infrastructure support.

Furthermore, previous studies tend to examine digital learning practices, digital resources, teacher competencies, or infrastructure support as separate variables or isolated factors(Nguyễn et al., 2023)(Mintasih et al., 2024)(J. Zhang & Zhang, 2024). Although the literature acknowledges that the success of digital learning depends on the interaction between teachers, technology, and school support systems, few studies have explored these interrelated dimensions simultaneously within a single school context. Therefore, there is still a need for empirical research to examine how teachers implement digital learning, utilize digital learning resources and platforms, understand infrastructure support, and overcome implementation challenges in vocational education settings. Addressing this gap could provide a more comprehensive understanding of the digital learning ecosystem in vocational high schools and generate practical insights to strengthen digital learning implementation at the school level.

In light of this gap, a more contextual comprehension of digital learning implementation in vocational education is needed. Although prior research has yielded significant insights into technology integration, digital competency, and infrastructure readiness, there is a paucity of studies investigating the interplay of these variables within the daily teaching practices of vocational high school educators. Comprehending educators' perspectives is essential, as they are pivotal in converting technical resources and institutional support into significant learning opportunities for students. This study seeks to examine teachers' experiences in the deployment of digital learning in vocational high schools and to determine the elements that facilitate and obstruct its execution. This study aims to: (1) identify digital learning practices employed by educators; (2) analyze digital learning resources and technological platforms utilized in instructional activities; (3) assess the impact of school infrastructure on the facilitation of digital learning; and (4) examine the challenges encountered by educators and the adaptive strategies they employ in the implementation of digital learning.

METHODS

This study employed a qualitative case study methodology (Terrell, 2015). This method is particularly suitable as it enables researchers to comprehensively investigate a case within its real-world environment, taking into account multiple interconnected elements. Case studies offer academics an opportunity to directly capture teachers' perspectives, comprehend the intricacies of the digital learning process at vocational institutions, and elucidate the interplay of pedagogical methods, technology, and the educational setting.

This study was performed at a vocational institution in the Magetan area that has adopted digital education via digital platforms, online learning materials, and technology-enhanced learning activities. This vocational institution was chosen due to its pertinent background for examining digital learning methodologies in vocational education, encompassing the application of digital technology and its supporting infrastructure. Participants were chosen by purposive

sampling to guarantee they possessed direct expertise and knowledge pertinent to the implementation of digital learning (Gill, 2020). The selection criterion mandated that teacher participants be actively engaged in digital learning activities, whilst administrative and infrastructural workers were chosen based on their roles in administering and supporting technological resources inside the school. The study involved five to six participants, comprising two vocational subject instructors, two general subject teachers, and one to two administrative or infrastructure staff members. The involvement of participants allowed the study to gather insights on digital learning methods, digital resources and platforms, infrastructure support, and implementation issues from both teaching and institutional viewpoints.

The data came from semi-structured interviews and observations. Participants' experiences, perceptions, and practices regarding digital learning implementation, including digital learning resources, technology platforms, infrastructure support, and teaching and learning challenges, were examined in semi-structured interviews. A customizable interview guide enables participants to comment on personal experiences while meeting study objectives. To supplement the interview data, observations were made of digital learning facilities, technology use in education, and the learning environment that supports digital learning in schools (Chand, 2025). Based on the study objectives and research questions, an interview guide and observation checklist were created. The teacher interview guide covered digital learning practices, tools and platforms, infrastructure support, and difficulties and adaption techniques. Administrative and infrastructure personnel interview guides stressed technical facilities and institutional support for digital learning. An observation checklist was utilized to assess the school's digital infrastructure, learning technologies, and learning environment in addition to interview data. Tables 1–3 show instrument characteristics and indicators.

Table 1. Interview Guide for Teachers

Aspect	Indicators
Digital Learning Practices	Planning of digital learning activities Implementation of digital learning practices Assessment and feedback in digital learning
Digital Learning Resources and Platforms	Types of digital platforms used Digital learning resources utilized Reasons for selecting digital resources and platforms
Infrastructure Support	Availability of digital learning facilities Accessibility of technology and internet resources Technical support provided by the school
Challenges and Adaptation Strategies	Technical challenges Pedagogical challenges Student-related challenges Adaptation strategies employed by teachers

Table 2. Interview Guide for Administrative/Infrastructure Staff

Aspect	Indicators
Infrastructure Support	Availability of ICT facilities Internet connectivity Availability of digital equipment Maintenance of technological facilities
School Support for Digital Learning	Technical support services Infrastructure development initiatives Challenges in infrastructure management

Table 3. Observation Checklist

Aspect	Indicators
Digital Infrastructure	Computer laboratory facilities Internet access Wi-Fi coverage Availability of digital devices
Learning Technology	Availability of LMS Use of learning applications Availability of digital learning resources
Learning Environment	Technology utilization in learning activities Accessibility of digital learning facilities

The collected data were analyzed using thematic analysis following Braun and Clarke's framework, which includes data introduction, initial coding, theme development, theme review, theme definition and naming, and report writing (Gihar, 2022). Through this process, recurring patterns related to digital learning practices, digital resources and platforms, infrastructure support, and implementation challenges were identified and interpreted. To ensure the reliability of the findings, credibility was established through triangulation of sources and methods, while reliability was supported by maintaining an audit trail throughout the research process. Confirmability was enhanced through peer review of thematic coding and interpretation, and transferability was achieved by providing rich descriptions of the research context, participants, and findings to enable readers to assess the applicability of the results in similar educational settings.

RESULTS AND DISCUSSION

Results

1. Digital Learning Practices in Vocational High Schools

Thematic analysis demonstrated that digital technology has been seamlessly incorporated into the learning process, encompassing planning, implementation, and assessment. Teachers develop technology-supported learning activities that are customized to their learning objectives, select suitable platforms, and prepare digital learning materials during the planning phase. Vocational educators frequently implemented project-based activities, digital tutorials, and specialized software to develop industry-oriented learning experiences, while general subject teachers prioritized interactive learning materials and digital content that promoted conceptual comprehension and student engagement. Free availability, accessibility, simplicity of use, and pedagogical appropriateness were the primary factors that influenced the selection of platforms among participants.

Blended learning became the predominant learning approach during the implementation phase. In order to facilitate communication, content delivery, learning activities, and assignment submission, educators integrated digital platforms with in-person instruction. Digital tools were implemented to facilitate student-centered learning by means of interactive explorations, project-based assignments, collaborative activities, and asynchronous learning opportunities. Observational data further verified that digital technology was consistently integrated into classroom practices through the use of learning management systems, online resources, and digital communication channels that extended teacher-student interactions beyond classroom hours. Assessment practices also extensively implemented digital technologies. Online exams, digital assignments, project evaluations, and e-portfolios are among the digital tools that educators employ for formative and summative assessment. These platforms support more individualized assessment practices, facilitate progress monitoring, and enable timely feedback. In addition, participants reported that they had modified their assessment strategies in response

to the emergence of new challenges associated with digital learning, such as the increased use of artificial intelligence tools by students and concerns regarding academic integrity. In general, the results suggest that digital learning is not restricted to the utilization of technology during instruction; rather, it has been integrated into the planning, teaching, and assessment processes.

Table 4. Summary of Digital Learning Practices

Sub-theme	Initial Codes	Representative Excerpt	Source
Digital lesson planning	RPP_DIGITAL; VIDEO_TUTORIAL_MANDIRI; TEMPLATE_PROYEK	"I prepare the RPP along with tutorial video links and check all lab devices before class"	P1
Industry-aligned platform selection	TOOLS_RELEVAN_INDUSTRI; PLATFORM_GRATIS; OTONOMI_PEDAGOGIS	"I deliberately choose tools actually used in the industry, not just educational tools"	P2
Blended & flipped learning	BLENDED_LEARNING; FLIPPED_CLASSROOM; PROJECT_BASED	"Students watch the tutorial at home first; class time is focused on practice and problem-solving"	P1
Multimodal digital activities	PODCAST_PROJECT; KOLABORASI_DIGITAL; LITERASI_DIGITAL	"Students script, record, edit, and publish their podcast on Spotify"	P4
Digital formative assessment	QUIZZZ; GITHUB_COMMIT_TRACKING; OTOMASI_PENILAIAN	"Results go directly into an automatic spreadsheet"	P1, P3
Differentiated digital feedback	FEEDBACK_24JAM; LOOM_VIDEO_PERSONAL; PEER_ASSESSMENT	"I record a short explanation video and share it only with the student who needs it"	P2
AI-adaptive assessment	GPTZERO; AI_LITERACY_KRITIS; PROSES_BUKAN_PRODUK	"I now emphasize the writing process — draft, revision, and reflection"	P4

2. Utilization of Digital Learning Resources and Technology Platforms

Interviews and classroom observations showed layered and autonomous platform adoption by teachers. Google Workspace for Education—Google Classroom, Google Meet, and Google Drive—was the institutional backbone of digital education, embraced by all four teachers. Beyond this shared ecosystem, platform selection varies by subject, demonstrating teachers' conscious efforts to match tools to their subjects. Vocational teachers used industry-standard tools. P1 simulated networks with Cisco Packet Tracer and GNS3, whereas P2 created an integrated development environment with GitHub, Replit, Discord, and VS Code Live Share to mimic software engineering practices. General subject teachers employed educational platforms: P3 used GeoGebra and Desmos for math visualizations and Khan Academy as an asynchronous resource, while P4 used Padlet, Canva, Audacity, and Anchor for literacy and creative production. Digital learning resources varied. Screencast recordings, PowerPoint-based video lectures, and YouTube tutorial videos were the main learning medium for all participants, supplemented with Khan Academy's selected open-access materials and subject-specific digital journals. A local server with 340 PDF modules, 120 video courses (~18GB), and 45 project templates, accessible via the school LAN, provided resistance against internet dependency. All observed classrooms used Google Classroom, not a school-owned or home-developed LMS.

The selection of platforms and resources was determined by three interconnected criteria consistently expressed by participants: student accessibility (particularly the availability of free versions), user-friendliness without necessitating extensive technical training, and congruence

with learning objectives—encompassing both vocational competency standards and disciplinary literacy aims. Institutional elements, including existing Google Workspace subscriptions in schools and the availability of GitHub Education Packs, enabled the adoption of certain platforms, but individual educators occasionally financed premium services independently in the absence of institutional backing.

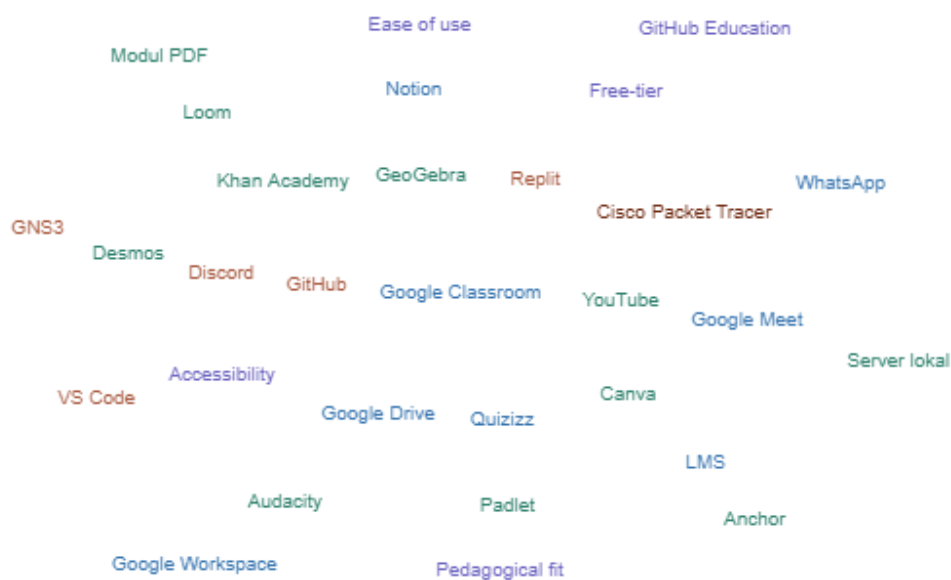


Figure 1. Word Cloud Results

3. Infrastructure Support for Digital Learning

Classroom observations and interviews with teachers, administrative staff and infrastructure personnel show that the school has a digital infrastructure that is usually competent to support digital learning, although access and quality vary among learning contexts. The school has two computer laboratories, classroom projection equipment, an interactive multimedia room and a local digital repository of learning modules, instructional videos and project-based learning material. Two internet service providers and a fiber-optic network guarantee internet connectivity, giving stable access to digital platforms and online resources. But investigations showed variation in internet performance between sites, with laboratory spaces obtaining far higher connectivity than conventional classrooms, especially ones in older school buildings. Wi-Fi coverage is provided in most locations of the school, while certain places suffer lesser connectivity.

In addition to the physical infrastructure, the school provides organized technical and institutional assistance for the implementation of digital learning. The IT coordinator deals with technological problems and regular maintenance. Coordination between administrative staff and school leaders and technical staff allows planning of infrastructure and allocation of resources. The school also spends part of its operating budget on ICT development and employs free educational technology resources to enhance digital learning opportunities.

On the whole, teachers said that the infrastructure available was sufficient to enable digital learning activities, especially for those with frequent access to computer laboratories and specialist software. But there are also certain hurdles, like a lack of quality facilities outside the lab setting, limits on lab time, intermittent internet connectivity in classrooms, and unequal access to personal digital devices by students. These findings imply that, despite the presence

of viable digital learning ecosystems in schools, the inequalities in infrastructure access continue to influence teachers' experiences and the practices of digital learning implementation.

Table 5. Thematic Coding Summary: Infrastructure Support for Digital Learning

Sub-theme	Initial Codes	Representative Excerpt	Source
Laboratory facilities & equipment	LAB_TERSEDIA; KETIDAKSETARAAN_KONDISI_LAB; PERANGKAT_USANG_LAB1; LAB2_BERFUNGSI_BAIK	"Lab 1: 4 units non-functional, 8 frequently hang. Lab 2: all units active and in good condition"	OBS
Internet connectivity & distribution	JARINGAN_FIBER_OPTIC; REDUNDANSI_INTERNET; DISPARITAS_KECEPATAN_INTERNET; WIFI_TIDAK_MERATA	"Wi-Fi covers about 80% of the school, but there are still dead zones in the old building"	P5, OBS
Local digital content repository	KONTEN_LOKAL_TERSEDIA; REPOSITORI_OFFLINE; VOLUME_KONTEN_SIGNIFIKAN	"The local server is very useful when the internet is slow"	P5
Technical support system	RESPONS_CEPAT_TEKNIS; SLA_INFORMAL; PEMELIHARAAN_BERKALA; SISTEM_IMAGING	"Critical issues are resolved in 15 minutes; non-critical within 24 hours"	P5
Institutional coordination & funding	KOORDINASI_ANTAR_UNIT; ALOKASI_BOS_TIK; KOLABORASI_STAKEHOLDER	"Around 15–20% of BOS funds are allocated to ICT development"	P6
Perceived adequacy — vocational teachers	KAPASITAS_PERANGKAT_CUKUP; GITHUB_EDUCATION_PACK; DUKUNGAN_SOFTWARE	"The school was willing to subscribe to the GitHub Education Pack"	P2
Perceived adequacy — general teachers	WIFI_TIDAK_STABIL_KELAS; HOTSPOT_PIBADI; PROPOSAL_BELUM_DITINDAKLANJUTI	"I often bring my own hotspot as a backup because the Wi-Fi in regular classrooms is not always stable"	P3
Student access inequity	KESENJANGAN_AKSES_SISWA; KEPEMILIKAN_PERANGKAT_BERVARIASI; AKSES_LAB_TERBATAS	"On average only 60–70% of students bring a device to regular classrooms"	OBS

4. Challenges and Adaptation Strategies in Digital Learning

Teachers struggle with technical, pedagogical, and human resource issues. Technical issues include unreliable internet connectivity in conventional classrooms, limited access to high-performance devices, and unequal student ownership of personal digital devices, which hinder technology-enhanced learning. Teachers have trouble monitoring students' understanding and involvement in digital learning settings, especially with copy-paste, AI technologies, and digital competency levels. Some participants worried that overusing digital technologies could hurt pupils' core skills. HR issues were less prevalent but included insufficient structured professional development and the necessity for teachers to independently build their digital competencies and acquire new technical tools.

Teachers used several adaptations to overcome these obstacles. Offline learning materials, cloud-based and browser-accessible apps, and digital resource optimization solved technical issues. Teachers used differentiated instruction, supported kids with learning disabilities, and gave high-achieving students more challenging assignments. Gamification and peer-assisted learning are also utilized to engage students and provide learning support outside of class. Some teachers promote AI literacy and ethical usage of AI tools in response to the rise of AI in education. These findings imply that teachers are adapting to digital learning issues by integrating technology, pedagogy, and collaborative tactics to sustain relevant learning experiences.

The results of all four research questions suggest that digitally engaged instructors are operating within a structurally unequal institutional environment. Blended and reversed learning models are well-established, and digitally mediated assessment practices are becoming increasingly prevalent. Digital learning practices are sophisticated and pedagogically intentional. Industry-relevant and discipline-specific tools are selected primarily for pedagogical alignment and accessibility, while platform adoption is broad and differentiated by subject. The foundation of this adoption is Google Workspace. In laboratory contexts, infrastructure support is functionally adequate; however, it is severely restricted in regular classrooms due to the persistent barriers of uneven connectivity, device access, and scheduling. Teachers exhibit a significant adaptive capacity in overcoming these constraints by utilizing alternative solutions beyond the internet, differentiated learning, gamification, peer-to-peer learning structures, and the integration of emerging AI literacies. These strategies, in general, reflect a pragmatic and professionally autonomous response to the complex realities of implementing digital learning in a public vocational high school context.

Discussion

The results of this study suggest that digital learning in vocational high schools has evolved beyond the mere use of instrumental technology, becoming a systematically integrated aspect of teachers' pedagogical practices throughout the entire learning cycle, including planning, implementation, and assessment. This is consistent with the findings of Akram et al. (2022), who demonstrated that educators who have a positive attitude toward digital technology are more likely to create interactive and student-centered courses by utilizing digital and multimedia platforms for instruction and feedback. The uniform implementation of blended learning among all participants is consistent with the findings of Nguyễn et al. (2022), who identified blended models as a learning framework that is becoming increasingly prevalent in digitally mature school environments. This framework facilitates the integration of asynchronous digital activities with face-to-face engagement. The capacity of teachers to intentionally integrate digital tools into subject-specific pedagogical approaches is a critical factor in the sustained digital integration at the classroom level, as demonstrated by the varying platform choices of vocational and general subject teachers in this study (Lomos et al., 2023). These results substantiate the argument Alenezi (2023) that a genuine digital transformation necessitates a transition from the perception of technology as a complement to the perception of it as an essential component of the learning process. This suggests that digital learning has become an essential aspect of everyday pedagogical practice in vocational high schools, with significant implications for teacher professional development, curriculum design, and institutional support.

In this study, teachers' platform selection was consistently influenced by three pragmatic criteria: accessibility, simplicity of use, and pedagogical appropriateness, rather than the sophistication or novelty of the technology. This pattern is consistent with the findings of Dahalan et al. (2023), who discovered that the deliberate alignment of technological tools with job competency standards and authentic workplace practices is a defining characteristic of effective digital integration in vocational education. This orientation is reflected in the adoption

of industry-standard tools by vocational instructors, who position digital platforms not only as teaching aids but also as simulated professional environments that connect classroom learning and industry expectations. Examples of such tools include GitHub, Cisco Packet Tracer, and Replit. These findings are in accordance with Barboutidis & Stiakakis (2023), who contend that vocational educators are increasingly anticipated to act as intermediaries between the evolving industry technologies and classroom pedagogy, which requires the selection of tools that emulate real-world digital workflows. In contrast, general subject teachers prioritized platforms that facilitate conceptual visualization and creative production, such as GeoGebra, Desmos, Canva, and Audacity. This distinction is consistent with the perspective of Rauseo et al. (2023), who underscored the significance of aligning digital resources with the epistemic requirements of specific subject areas rather than implementing uniform technological solutions across disciplines. This study's discovery that the selection of context-appropriate tools promotes meaningful digital integration was further supported by the fact that student engagement and learning outcomes were more strongly correlated with the pedagogical coherence of platform use than with technological complexity (Noguera et al., 2024). Collectively, these results indicate that educators serve as instructional designers, making deliberate and context-sensitive decisions regarding the integration of technology that are consistent with the unique learning characteristics and competency requirements of general academic and vocational subjects.

Despite the school's relatively adequate digital infrastructure, which included computer laboratories, internet connectivity, and digital learning resources, the results indicate that infrastructure alone does not ensure the equitable or effective implementation of digital learning. The capacity of teachers to conduct technology-intensive learning activities outside the laboratory environment was restricted by the uneven Wi-Fi coverage, unequal pupil access to digital devices, and differences in internet performance across classrooms. These results corroborate prior research that underscores the significance of infrastructure quality and equitable access in determining the efficacy of digital learning (Nguyễn et al., 2023)(Mintasih et al., 2024). However, the mere presence of facilities does not necessarily result in meaningful pedagogical integration (Woltran et al., 2022)(J. Zhang & Zhang, 2024). This study emphasizes the adaptive capacity of instructors as a critical factor in the implementation of digital learning. Teachers devised a variety of strategies in response to technical, pedagogical, and resource-related limitations, such as the integration of AI literacy, differentiated learning, gamification, peer-assisted learning, and offline learning repositories. These results bolster the argument that sustainable digital learning is contingent upon the active participation of instructors, adaptive skills, and pedagogical flexibility, in addition to the provision of technology (Kaimara et al., 2021)(Stringer et al., 2022). Thus, the interaction between institutional support and instructors' ability to creatively transform available resources into meaningful learning opportunities appears to be a determining factor in the success of digital learning in vocational education.

Overall, the findings of this study indicate that the implementation of digital learning in vocational high schools cannot be adequately understood through a single factor. Rather, the evidence points to an interconnected ecosystem in which infrastructure support, digital resources and platforms, teaching practices, teacher adaptation strategies, and institutional support operate as interconnected elements. When one component is hampered, as seen in cases of uneven connectivity or device access, the effectiveness of the broader system depends on compensatory mechanisms elsewhere, particularly teacher adaptability. This systemic interdependence extends and contextualizes existing digital integration frameworks by demonstrating that in resource-diverse public-school environments, the coherence of the overall ecosystem is more important than the strength of any individual component. Thus, this study provides a context-based conceptual explanation of the implementation of digital learning in vocational education, highlighting the dynamic interactions between teachers, technology, and institutional conditions as mechanisms shaping a functional digital learning ecosystem.

CONCLUSION

This investigation demonstrates that the integration of digital learning into vocational high schools has become an essential component of the daily learning process, encompassing the planning, implementation, and evaluation phases. Teachers employ a variety of digital learning platforms and resources in a strategic manner, determining their suitability for learning objectives, simplicity of use, and accessibility. While schools have provided infrastructure support that is relatively adequate, there are still a number of obstacles that are associated with the equitable use of digital facilities, the availability of devices, and the accessibility of the internet in different learning environments. The research results also suggest that the implementation of digital learning is not necessarily impeded by technical, pedagogical, or human resource challenges. Rather, educators exhibit a high level of adaptive capacity by incorporating artificial intelligence literacy, gamification, peer-based learning, differentiated learning, and alternative learning resources into the learning process. This study demonstrates that the success of digital learning in vocational education is not solely influenced by the availability of technology, but rather by the dynamic interaction between teachers' pedagogical practices, digital resources, infrastructure support, and their adaptability in creating meaningful learning experiences. These results suggest that the digital learning ecosystem in vocational schools must be holistically strengthened by enhancing the digital competencies of instructors, ensuring equal access to infrastructure, and establishing school policies that encourage technology-based learning innovation.

CONFLICT OF INTEREST

The authors declare there are no conflict of interest.

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The Influence of Project Based Learning Strategy on Learning Outcomes in Computer Science Subjects at Vocational High School

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ABSTRACT

Technological developments in the Industrial Revolution 4.0 era require the world of education to implement learning strategies that can improve critical thinking skills and student creativity, especially in Informatics subjects in Vocational High Schools (SMK), but the dominance of conventional strategies causes student learning outcomes to be less than optimal. This study aims to examine the improvement, differences, and the effect of implementing Project Based Learning (PjBL) strategies on Informatics learning outcomes of class X Health Services students at SMK Negeri 1 Banyudono. This study used a quantitative approach with a quasi-experimental design, involving class X LK 1 as the experimental class receiving the PjBL strategy and class X LK 2 as the control class using conventional learning. Data collection used a pre-test and post-test, then analyzed using paired sample t-tests, independent sample t-tests, and the N-Gain test. The results indicated a significant increase in learning outcomes in the experimental class with a calculated t-value of 23.610, and a significant difference between the experimental and control classes with a calculated t-value of 10.915. The average N-Gain value of 0.55 is in the moderate category. Based on these findings, it is concluded that the Project Based Learning strategy has been proven to have a significant influence on student learning outcomes through collaborative activities and project completion, thus potentially being an effective alternative learning strategy in informatics subjects.

Keywords: Project Based Learning, learning outcomes, Informatics, quasi-experiment, vocational high school



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INTRODUCTION

The rapid development of technology in the era of the Fourth Industrial Revolution has accelerated digitalization and the integration of intelligent systems across various sectors. This transformation requires a workforce equipped with adaptive, analytical, and innovative competencies to meet the demands of the modern industry (Yanti et al., 2024). Consequently, educational institutions are expected to adopt learning approaches that align graduates' competencies with the needs of technology-driven and future-oriented industries (Kasili et al., 2025). Setyaningsih (2023) highlights that contemporary digital multimedia developments have evolved beyond basic audio and text to encompass highly integrated formats of graphics, animations, images, and audio/video, creating an extraordinary impact on learning resources

across international boundaries. Furthermore, future innovations such as the metaverse are emerging as 3D shared virtual spaces that promise highly immersive and interactive experiences for global education (Alhakimi, 2023). This digital transformation marks a significant turning point in pedagogy, where the shift to screen-to-screen interactions places educational technology in a crucial role to facilitate flexible and meaningful environments (Peramtasari, 2023). This adaptation is further supported by cloud computing technologies such as Google Forms, Quizizz, and Wordwall, which enhance the fundamental efficiency, engagement, and outcome quality within informatics education at vocational schools (Purnama et al., 2024).

Vocational High Schools (SMK) play a strategic role in preparing skilled graduates who are not only proficient in technical competencies but also possess essential 21st-century skills, including communication, collaboration, creativity, and critical thinking (Rahmi et al., 2023). Career development and entrepreneurial intentions among vocational graduates in this digital era are heavily determined by their capacity to solve complex technical problems, handle advanced applications, and navigate digital services effectively (Vitariyanti et al., 2024). To establish this high-level adaptive capacity, proper control, guidance, and exposure to technological toolsets should ideally serve as a foundational anchor during early childhood development and informal education phases (Pinilih, 2023). In secondary education environments, teachers must act not only as instructional transmitters but also as crucial role models who instill emotional intelligence, responsibility, and core ethical values to help students establish healthy peer relationships and navigate conflicts constructively (Septyventia et al., 2024). However, despite improvements in national educational indicators, learning outcomes in vocational education remain a concern. Previous reports indicated that vocational students demonstrated relatively low academic achievement in both general and vocational subjects, highlighting the need for more effective instructional strategies (Puspendik, 2019). This learning deficiency is often exacerbated by conventional, unvaried teaching habits that result in student disengagement (Fitriani & Ridhani, 2025). To overcome classroom boredom and accommodate highly diverse learning styles in the post-pandemic era, creative teaching variations combining novel methods, digital media, and adaptive interactions are vital to building inclusive classrooms (Arifin et al., 2025).

Similar conditions were identified at SMK Negeri 1 Banyudono. Preliminary data from Informatics classes revealed that a considerable proportion of students had not achieved the Minimum Completeness Criteria (KKM). Classroom observations further indicated that learning activities were predominantly teacher-centered, relying heavily on lecture-based instruction. Such conventional practices tend to limit students' active participation, reduce learning motivation, and hinder the development of deeper conceptual understanding. Real-world challenges indicate that formative computational thinking assessments remain in their infancy, revealing deep conceptual gaps regarding how digital tools are leveraged, while learning management systems are frequently underutilized as metacognitive scaffolding instruments (Buwono et al., 2025). These challenges emphasize the importance of implementing innovative learning strategies that promote active and meaningful learning experiences. One relevant direction involves systemically developed multimedia tools, such as digital flipbooks mapped to the Dick & Carey instructional design model, which have proven highly valid and capable of boosting creative problem-solving fluency and engagement (Yasni et al., 2025). Similarly, structured digital management systems such as the Nearpod platform, when structured through systematic instructional design, have demonstrated significant success in supporting high-order cognitive processes and critical thinking (Sasongko et al., 2025). On an experiential level, holistic instructional frameworks like the BERAKSI model (Playing, Creating, Discussing, and Cheerful) confirm that multi-activity engagement fosters a pleasant, dynamic atmosphere that significantly optimizes student immersion (Nongko et al., 2025).

In line with national educational goals, students are expected to develop critical thinking, creativity, collaboration, and communication skills through student-centered learning approaches. One strategy that supports these objectives is Project-Based Learning (PjBL). PjBL engages students in authentic projects, encouraging active participation, collaboration, and problem-solving throughout the learning process (Hera Erisa et al., 2021). The educational value of action-based innovations is mirrored in Game-Based Learning (GBL) models that merge ADDIE principles with discovery learning to simulate authentic vocational scenarios, significantly maximizing logical thinking and preparing graduates for real job markets (Raziana & Wibawanto, 2025). By targeting concrete project outcomes, PjBL fosters a parallel constructivist environment. Previous studies have demonstrated that PjBL can improve critical thinking skills, creativity, learning motivation, and academic achievement compared to conventional instructional methods (Salman et al., 2020). Although numerous studies have examined the implementation of PjBL in vocational education, most have employed Classroom Action Research designs, which provide findings limited to specific contexts. Experimental studies investigating the effectiveness of PjBL in improving Informatics learning outcomes remain limited. Therefore, this study aims to examine the effect of Project-Based Learning on students' learning outcomes in Informatics through a quasi-experimental design, providing stronger empirical evidence regarding the effectiveness of PjBL in vocational education settings.

METHODS

This study was conducted at SMK Negeri 1 Banyudono, located at Jl. Kuwiran No. 3, Banyudono, Boyolali Regency, Central Java, Indonesia. The school was selected as the research site because the learning strategies implemented in Informatics classes were considered less optimal, resulting in suboptimal student learning outcomes.

This study employed a quasi-experimental design involving 68 tenth-grade students, consisting of 35 students in the control class and 33 students in the experimental class. The participants were selected using purposive sampling. Data were collected through pre-tests and post-tests to examine the effects of the implemented learning strategies on students' learning outcomes. The research instruments were validated through validity and reliability testing prior to data collection.

Data analysis included normality and homogeneity tests, followed by hypothesis testing using paired sample t-tests, independent sample t-tests, and N-gain analysis. The research procedure consisted of four stages: preparation, implementation of the intervention, data analysis, and conclusion drawing.

RESULTS AND DISCUSSION

Results

This study aimed to examine the effect of the Project-Based Learning (PjBL) strategy on students' learning outcomes in Informatics at SMK Negeri 1 Banyudono. The effectiveness of PjBL was analyzed using paired sample t-tests, independent sample t-tests, and N-Gain analysis.

Table 1. Results of Paired Sample t-Test

Analysis Component	Value
Mean Difference (Pre–post-test)	21.143
Standard Deviation	5.298
t-value	23.610
df	34
Sig. (2-tailed)	0.001

The paired sample t-test revealed a mean difference of 21.143 between pre-test and post-test scores, indicating a substantial improvement in students' learning outcomes after the implementation of PjBL. The obtained t-value was 23.610 with a significance value of 0.001 ($p < 0.05$), demonstrating a statistically significant difference between pre-test and post-test scores. These findings indicate that the PjBL strategy effectively improved students' Informatics learning outcomes in the experimental class.

To compare learning outcomes between students taught using PjBL and those receiving conventional instruction, an independent sample t-test was conducted.

Table 2. Results of Independent Sample t-Test

Analysis Component	Value
Levene's Test (F)	0.032
Levene's Sig.	0.859
t-value	10.915
df	66
Sig. (2-tailed)	0.001

The Levene's test significance value of 0.859 ($p > 0.05$) indicated homogeneity of variance between the two groups. Therefore, the equal variances assumed criterion was applied. The independent sample t-test yielded a t-value of 10.915 with a significance value of 0.001 ($p < 0.05$), indicating a significant difference in learning outcomes between the experimental and control groups. Students who learned through the PjBL strategy achieved significantly better learning outcomes than those who experienced conventional learning.

Furthermore, N-Gain analysis was performed to determine the effectiveness of PjBL in improving students' learning outcomes. The analysis involved 35 students in the experimental class. The N-Gain scores ranged from 0.25 to 0.75, with a mean score of 0.5548 and a standard deviation of 0.09875. Based on the N-Gain interpretation criteria, this result falls within the moderate category, suggesting that PjBL was moderately effective in enhancing students' Informatics learning outcomes.

Discussion

The descriptive analysis revealed a substantial improvement in students' learning outcomes following the implementation of Project-Based Learning (PjBL). The mean score increased from 62.29 on the pre-test to 83.43 on the post-test, indicating an improvement of 21.14 points. Similar improvements were observed in other descriptive statistics, including increases in the minimum score (50 to 80), maximum score (80 to 90), median (65 to 85), and mode (65 to 80–85). These findings suggest that PjBL promotes active student engagement and enhances understanding of Informatics concepts through meaningful learning experiences.

The findings support Vygotsky's social constructivist theory, which emphasizes that knowledge is constructed through social interaction and collaborative learning processes (Rusman, 2020). The concept of the Zone of Proximal Development (ZPD) suggests that students achieve optimal learning outcomes when appropriate guidance and peer support are provided. In the implementation of PjBL, students actively engaged in discussions, collaboration, and project completion, enabling them to construct knowledge more effectively and apply concepts in authentic contexts. The profound impact of this structured scaffolding is mirrored when Problem-Based Learning is combined with differentiated instructions matching students' initial capacities and ZPD limits, showing an exceptional increase in active participation, independent task completion, and overall positive academic attitudes (Pawitra et al., 2025). The practical implications of such interactive adjustments match the success observed in cooperative

structures like the Numbered Head Together method, which utilizes targeted media to significantly improve classroom engagement, successfully lifting classic learning completeness from low thresholds to fully realized benchmarks (Fitriani & Ridhani, 2025).

The effectiveness of PjBL was further confirmed by the paired sample t-test results. The mean difference of 21.143 and the significant t-value ($t = 23.610$, $p < 0.001$) indicate that students' learning outcomes improved significantly after the intervention. Moreover, the 95% confidence interval did not cross zero, demonstrating the consistency of the observed improvement. These results indicate that PjBL not only facilitates theoretical understanding but also provides students with direct learning experiences through project-based activities related to Informatics content. This clear cognitive improvement satisfies the intense demands brought by modern digital multimedia shifts, which compel modern educators to design environments that naturally spark digital knowledge creation (Setyaningsih, 2023). Grounding PjBL instruction within authentic project workflows addresses the critical requirement for systematic, multimedia-supported learning environments that have been empirically shown to foster complex creative thinking skills in 21st-century classrooms (Yasni et al., 2025).

Comparative analysis between the experimental and control groups also demonstrated the superiority of PjBL over conventional instruction. The experimental group achieved a higher mean post-test score (83.43) compared to the control group (73.64). The independent sample t-test yielded a significant difference between the two groups ($t = 10.915$, $p < 0.001$), while Levene's test confirmed the homogeneity of variance ($p = 0.859$). In addition, the average N-Gain score of 0.5548 was categorized as moderate, indicating that PjBL was moderately effective in improving students' learning outcomes in Informatics. The fact that PjBL yields superior results compared to teacher-centered structures carries substantial implications for tactical curriculum changes in vocational schools. It emphasizes that incorporating highly adaptive, inclusive, and multi-method pedagogical frameworks is the primary mechanism to combat student boredom and harmonize instructions with highly varied student learning profiles (Arifin et al., 2025). By allowing students the freedom to navigate hands-on digital artifacts, the learning environment transforms into a dynamic space optimized for real-world competency growth.

These findings are consistent with previous studies reporting the positive impact of PjBL on students' academic achievement. Surbakti et al. (2023) found that the implementation of PjBL significantly improved Informatics learning outcomes, with students' average scores increasing from 52.63 to 83.40. Similar to the present study, their research employed PjBL as the instructional intervention and learning outcomes as the primary variable of interest. However, this study contributes additional empirical evidence by focusing on vocational education settings, specifically tenth-grade Health Services students at SMK Negeri 1 Banyudono. This provides an important theoretical bridging effect, aligning with modern digital instructional management approaches that establish a direct link between strategic design platforms and high-order cognitive development (Sasongko et al., 2025). Therefore, the findings strengthen existing evidence regarding the effectiveness of PjBL in enhancing learning outcomes within vocational Informatics education while offering concrete operational solutions to the structural limitations of conventional systems that limit student potential.

Overall, the results indicate significant differences in learning outcomes before and after the implementation of PjBL, as well as between students taught using PjBL and those receiving conventional instruction. These findings confirm that Project-Based Learning is both statistically and practically effective in improving Informatics learning outcomes among vocational high school students.

CONCLUSION

This study demonstrates that the implementation of Project-Based Learning (PjBL) has a positive and significant effect on students' learning outcomes in Informatics at SMK Negeri 1 Banyudono.

The paired sample t-test results revealed a significant improvement in learning outcomes after the implementation of PjBL, while the independent sample t-test indicated a significant difference between the experimental and control groups, with the experimental class achieving higher post-test scores. Furthermore, the N-Gain analysis yielded an average score of 0.5548, categorized as moderate, suggesting that PjBL was moderately effective in enhancing students' learning outcomes. The integration of current empirical literature indicates that this instructional success is driven by fulfilling the critical demands for multimodal learning tools, adaptive digital environments, and student-centered project execution. These findings confirm that Project-Based Learning can serve as an exceptionally robust and adaptive instructional strategy to enhance learning outcomes and cultivate core modern competencies within vocational high school informatics systems.

CONFLICT OF INTEREST

The authors declare no competing financial, professional, or personal interests that might have influenced the performance or presentation of the work described in this manuscript.

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An Analysis of Readiness of Teacher At MAN 2 Tapanuli Tengah In Facing Education Digital Transformation

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ABSTRACT

The digital transformation in education requires teachers to be well-prepared in adopting technology as an effective teaching medium and method. The study aims to analyze the readiness of teachers at MAN 2 Tapanuli Tengah in facing the digital transformation of education, focusing on three key aspects: technological competence, attitudes and motivation, and supporting facilities and infrastructure. This research employs a quantitative approach with a descriptive method. Data were collected through questionnaires, interviews, and observations involving 35 teacher respondents. The results indicate that the overall readiness of teachers at MAN 2 Tapanuli Tengah is categorized as "Ready," with an average readiness in technological competence of 71.57%, attitudes and motivation at 79.43%, and facilities and infrastructure at 60.29%. These findings suggest that teachers possess adequate abilities and motivation to adapt to technological changes; however, the school needs to improve the availability of supporting facilities such as stable internet networks and digital devices. This study recommends continuous professional development for teachers and the enhancement of digital infrastructure to ensure the success of educational digital transformation in the madrasah environment.

Keywords: *Teacher Readness, Digital Transformation, Technological Competence.*



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INTRODUCTION

The rapid development of information and communication technology has brought major changes in various aspects of life, including in the world of education. The learning process, which used to be dominated by conventional face-to-face methods, is now starting to shift towards a digital learning system that utilizes various technology-based platforms and media. The government through the Ministry of Education, Culture, Research and Technology has encouraged educational units to carry out digital transformation to improve the quality and access to education, one of which is through the school digitization program and the *Kurikulum Merdeka*.

In this modern landscape, digital multimedia has drastically evolved from mere sound and text into integrated graphics, animation, and video systems that enable users to interact and communicate seamlessly across regional boundaries (Setyaningsih, 2023). Consequently,

interactive digital media must be strategically developed to deliver multimodal learning that can foster crucial 21st-century competencies, such as student engagement and creative problem-solving skills (Yasni et al., 2025).

Madrasah Aliyah Negeri (MAN) 2 Tapanuli Tengah as an Islamic educational institution is also required to be able to adapt and innovate along with the changing times. Digital transformation of education in Madrasah Aliyah is an important step to prepare a generation that not only has a strong religious understanding but also has adequate digital skills to compete in the global era. In this context, teachers play a central role as facilitators, innovators, and drivers of change in the madrasah environment.

To maintain a dynamic learning atmosphere and overcome student passivity, contemporary teachers are demanded to be highly creative in implementing instructional variations, including integrating diverse teaching styles, digital platforms, and adaptive media into their classrooms (Arifin et al., 2025). This instructional management shift is vital because scientific assessments consistently indicate a pressing need for systematic learning strategies that go beyond mere content transmission to actively elevate students' critical and higher-order thinking skills (Sasongko et al., 2025).

According to Venkatesh et al. (2021), the success of technology adoption in research is highly dependent on user readiness, in this case teachers and students. Teachers who have a good understanding of technology tend to be more confident in using it in the learning process. Conversely, lack of technological skills and resistance to change are the main obstacles in the process of digitizing education (Selwyn, 2020). Therefore, support in the form of continuous training and supportive policies are needed so that teachers can develop their skills in using technology optimally (Warschauer, 2021). Furthermore, the role of educators in this digital era expands into facilitating holistic student development, where teachers must also serve as supportive role models who integrate emotional intelligence and character values into the technology-enhanced curriculum (Septyventia et al., 2024).

On the other hand, social and cultural factors also play an important role in teacher readiness for digital transformation. According to Hall and Hord (2019), changes in the education system often experience resistance from those involved, including teachers who may feel comfortable with the conventional methods they have used for years. A positive attitude towards technological innovation is a key factor in the successful implementation of digital transformation. In addition, school policies and support from education stakeholders also play an important role in ensuring the smooth adoption of technology in Learning (Anderson, 2020). This pedagogical mastery over educational technology has become an absolute turning point since global shifts accelerated screen-to-screen learning, establishing digital tools as the primary means to enhance meaningful learning outcomes (Peramtasari, 2023).

However, the implementation of education digitization at MAN 2 Tapanuli Tengah has not been optimal. Based on observations and various reports in the field, many teachers still face obstacles in integrating technology into learning. Some of the factors that become obstacles include teachers' low digital literacy, limited training, lack of facilities, and resistance or fear of using new technology. This condition shows that teacher readiness in facing digital transformation is still a challenge that needs serious attention.

Teacher readiness in facing digital transformation is not only related to technical capabilities, but also includes mental readiness, attitudes towards change, and pedagogical skills in designing effective digital learning. Teachers must be able to utilize digital media to create

learning that is interactive, interesting, and relevant to the needs of students in the digital era. Without adequate readiness, the education digitalization program at MAN 2 Tapanuli Tengah risks becoming a formality without having a significant impact on improving the quality of education.

Based on the importance of the role of teachers in the success of digital transformation, research is needed that is able to analyze the extent of the readiness level of MAN 2 Tapanuli Tengah teachers, both in terms of technological skills, availability of infrastructure, as well as in terms of attitudes and motivation. The results of this study are expected to be used as evaluation and reference material in designing training programs and policies that are more targeted to accelerate the process of digitizing education in MAN 2 Tapanuli Tengah.

METHODS

This research is a descriptive quantitative study that aims to describe and analyze the level of readiness of MAN 2 Tapanuli Tengah teachers in facing the digital transformation of education. Descriptive research is used to describe factual conditions in the field, while the quantitative approach is used to measure the level of teacher readiness based on data collected through research instruments.

The population in this study were all teachers teaching at MAN 2 Tapanuli Tengah who were involved in the digital-based learning process. The sample was taken using the total sampling technique because the number of teachers at MAN 2 Tapanuli Tengah was relatively limited. All teachers who are willing and meet the criteria will be used as research respondents. The data collection techniques in this study are questionnaires, interviews, observation and documentation. The research instrument was prepared to measure the level of readiness of MAN 2 Tapanuli Tengah teachers in facing the digital transformation of education, which includes three main aspects, namely technological competence, attitudes and motivation, and facilities and infrastructure. Each aspect is translated into specific indicators and statements in the form of a questionnaire with a Likert scale.

Table 1. Indicators of Readiness of MAN 2 Tapanuli Tengah Teachers in Facing the Digital Transformation of Education.

No	Variable	Indicators	Item Number
1	Technological Competence	Ability to operate digital devices	1,2
		Ability to use e-learning applications	3,4
		Ability to create digital media	5,6
		Ability to manage digital classrooms	7,8
2	Attitude and Motivation	Enthusiastically participating in technology training	9,10
		Willingness to learn independently	11,12
		Mental readiness to face digital change	13,14
		The convenience of using technology in teaching	15,16
3	Facilities and Infrastructure	Availability of digital devices	17,18
		Internet network availability	19,20
		Availability of learning support applications	21,22
		Facility supports from madrasah	23,24

Note: All items are measured using a 5-point Likert scale ranging from 1 (Strongly Disagree / STS) to 5 (Strongly Agree / SS).

The importance of quantitative data analysis from questionnaire data and qualitative data analysis from interview and observation data were analyzed descriptively to support quantitative data. Furthermore, the item validity test was tested with Pearson Product Moment correlation. The instrument is declared valid if the value of $r_{count} > r_{table}$ at the 5% significance level. And reliability is tested using Alpha Cronbach. The instrument is declared reliable if the Alpha Cronbach value is > 0.6 .

RESULTS AND DISCUSSION

Results

This study was conducted to analyze the readiness of MAN 2 Tapanuli Tengah teachers in facing the digital transformation of education by focusing on three main aspects: technological competence, attitude and motivation, and availability of infrastructure. Data were collected through questionnaires filled out by 35 teachers, facility observations, and interviews with the madrasah head and several teachers.

1. Teachers' Technological Competence Readiness

The questionnaire on the technological competence aspect was given to 35 teachers of MAN 2 Tapanuli Tengah to find out the extent of their ability to operate digital devices, use e-learning applications, create digital learning media, and manage digital classes.

Table 2. Recapitulation of Questionnaire Data Teacher Technology Competence Readiness

No	Technology Competency Indicators	Maximum Score	Score Obtained	Percentage (%)	Categories
1	Operating a laptop/PC	175	145	82,86%	Very Ready
2	Using projectors and multimedia	175	135	77,14%	Ready
3	Using Google Classroom	175	130	74,29%	Ready
4	Using Zoom/Google Meet	175	125	71,43%	Ready
5	Creating educational videos	175	115	65,71%	Ready
6	Creating digital modules/teaching materials	175	110	62,86%	Ready
7	Managing digital classrooms	175	120	68,57%	Ready
8	Overcoming technical problems in digital learning	175	115	65,71%	Ready

Based on the questionnaire results, the average teacher readiness in the aspect of technological competence is in the "Ready" category (71.57%). Most teachers are able to operate laptops/PCs (82.86%) and use projectors (77.14%) in learning. Teachers are able to use Google Classroom (74.29%) and Zoom (71.43%) applications for online learning, but the application is still basic. Skills in creating digital media such as videos (65.71%) and interactive modules (62.86%) are still low. Mastery of digital classroom management and the ability to solve simple technical problems also still need to be improved.

According to Toran et al. (2010), technological readiness includes mastery of devices and mastery of digital systems to support learning. Fatmawati (2021) adds that teachers who are able to use digital media creatively will find it easier to adapt to the transformation of technology-based education.

2. Attitude Readiness and Teacher Motivation

Table 3. Recapitulation of Questionnaire Data Attitude Readiness and Teacher Motivation

No	Attitude and Motivation Indicators	Maximum Score	Score Obtained	Percentage (%)	Categories
1	Enthusiastically participating in technology training	175	149	85,14%	Very Ready
2	Willingness to learn independently about new technologies	175	140	80,00%	Ready
3	Changes in digital learning methods	175	136	77,71%	Ready
4	The convenience of using digital media in learning	175	131	74,86%	Ready

The average questionnaire results showed that teachers' attitudes and motivation were in the "Ready" category (79.5%). 85% of teachers are enthusiastic about digital training and willing to learn new technologies. 80% of teachers have a willingness to learn independently to develop digital skills. 78% of teachers are ready to accept the change in learning model from conventional to digital. 75% of teachers feel comfortable using technology in the learning process.

According to Rogers (2003) in the Diffusion of Innovation theory, technology acceptance is highly dependent on individual attitudes and readiness to adopt changes. Rahayu (2019) also emphasized that teacher motivation is key to the successful implementation of digital education. Without a positive attitude, technological transformation will be difficult to succeed even if facilities are available.

3. Readiness of Facilities and Infrastructure

Table 4. Recapitulation of Questionnaire Data Readiness of Facilities and Infrastructure

No	Facilities and Infrastructure Indicators	Maximum Score	Score Obtained	Percentage (%)	Categories
1	Availability of laptops/projectors in madrasah	175	123	70,29%	Ready
2	Adequate internet network availability	175	97	55,43%	Ready Enough
3	Ketersediaan Adequate e-learning application/platform	175	114	65,14%	Ready
4	Digital facility supports from madrasah	175	88	50,29%	Ready Enough

The average results of the questionnaire show that the readiness of facilities and infrastructure is in the "Quite Ready" category (60.29%). The availability of laptops/projectors (70.29%) is quite good, although their use is still alternating between teachers. Internet availability (55.43%) is the main problem that teachers often complain about, especially during peak hours. Madrasah have provided several learning applications (65.14%), but they are not well integrated. Support for digital facilities from madrasah (50.29%) is still relatively low and needs to be a concern for madrasah management.

According to Lubis (2020), facilities and infrastructure are important factors in realizing digital education transformation. Parsons et al. (2006) in the concept of Digital Readiness emphasizes that infrastructure readiness is an absolute requirement for the success of

educational digitalization. If the facilities are inadequate, then the application of technology will run half-heartedly.

Integration of Research Results

Overall, MAN 2 Tapanuli Tengah teachers are in the “Ready” category in facing the digital transformation of education in terms of competence and motivation. However, the support of facilities and infrastructure is still a major obstacle.

Table 5. Recapitulation of Readiness of Teacher of MAN 2 Tapanuli Tengah

No	Facilities and Infrastructure Indicators	Maximum Score	Score Obtained	Percentage (%)	Categories
1	Availability of laptops/projectors in madrasah	175	123	70,29%	Ready
2	Adequate internet network availability	175	97	55,43%	Ready Enough
3	Ketersediaan Adequate e-learning application/platform	175	114	65,14%	Ready
4	Digital facility supports from madrasah	175	88	50,29%	Ready Enough

Discussion

The empirical findings of this research present several critical insights regarding the digital transformation process at MAN 2 Tapanuli Tengah. First, the data proves that simple mastery of technology is not enough; rather, teachers urgently require specialized professional training focused on creating attractive, interactive digital media to truly enhance the learning experience. Second, the study highlights that the positive attitudes and high motivation displayed by the teachers at MAN 2 Tapanuli Tengah serve as the primary internal forces that can effectively drive and sustain the success of educational digitization. Finally, to prevent this professional enthusiasm from being bottlenecked, the readiness of the madrasah's infrastructure must be improved immediately, which requires comprehensive upgrades in terms of digital devices, stable internet networks, and active administrative management support.

The results show clear alignments and systemic frictions when contrasted against contemporary pedagogical literature. The finding that teachers display high basic competence (82.86% in laptop operations) but limited ability in creating interactive teaching materials (62.86%) underscores a major gap. Literature highlights that simple content dissemination is insufficient; modern instruction demands systematically managed strategies, interactive media like flipbooks, or specialized digital tools such as Nearpod to sustain 21st-century cognitive processes and elevate critical thinking (Sasongko et al., 2025; Yasni et al., 2025). By failing to design rich digital modules, teachers cannot establish the nuanced scaffolding required to build higher-order problem-solving skills (Buwono et al., 2025). This limitation implies an urgent need to transition teachers from passive technology users into active multimedia creators who combine text, animation, and video to enhance student knowledge acquisition (Setyaningsih, 2023).

Furthermore, the high motivation and enthusiastic attitude of teachers (85.14% participation in training) represent a potent internal asset. This willingness to adapt is crucial, as the modern educational climate demands that educators continually refine their methods, manage digital classrooms with emotional intelligence, and integrate sophisticated tools to eliminate student boredom (Arifin et al., 2025; Septyventia et al., 2024). However, this enthusiasm is severely hindered by the "Ready Enough" infrastructure status, particularly

regarding internet stability (55.43%). Educational technology theories indicate that infrastructure readiness is an absolute prerequisite; poor connectivity forces technology-based applications to perform inefficiently (Parsons et al., 2006). Without reliable cloud computing ecosystems or robust institutional networks, implementing sophisticated digital transformation frameworks, exploring Game-Based Learning, or adopting immersive spaces like the Metaverse will remain impossible (Purnama et al., 2024; Raziana & Wibawanto, 2025). Consequently, the gap at MAN 2 Tapanuli Tengah is not driven by teacher resistance, but by an infrastructure deficit that restricts teachers from adopting student-centered models like PBL-ZPD or implementing interactive games that align with current job market requirements (Pawitra et al., 2025; Vitariyanti et al., 2024).

CONCLUSION

The findings and analysis that have been carried out, can be concluded that first, MAN 2 Tapanuli Tengah teachers generally have basic competencies and high motivation in adopting digital technology. However, the results show that teachers still need to improve advanced digital skills, such as creating interactive learning media and effective digital classroom management. Regular training and technology workshops are essential so that teachers are not only users but also creative digital media developers. Teachers who are more prepared need to become mentors for colleagues who still face technical difficulties in order to accelerate technology adaptation.

Second, madrasah plays a crucial role in preparing facilities and infrastructure. The results show that facility support is still limited and the internet network is not optimal. The implication is that madrasah needs to increase the provision of digital devices such as laptops, projectors, and ensure the stability of the internet network in all classrooms. There should be a special budget for strengthening digitalization, such as providing an integrated e-learning platform and easily accessible learning applications. Madrasah needs to build a digital culture in the school environment by providing space and full support to teachers to experiment using technology in learning.

Third, for the Ministry of Religious Affairs or related agencies in charge of madrasah, it is necessary to develop a national program to strengthen the digitalization of madrasah, especially in areas with limited infrastructure. There should be an affirmation policy for madrasah with limited facilities to prioritize device assistance and internet network strengthening. Need to expand access to competency-based digital training that is integrated with the current needs of madrasah teachers.

Fourth, the curriculum at MAN 2 Tapanuli Tengah needs to start integrating digital-based learning systematically, not only as an addition or alternative. Teachers need to be directed to use blended learning or flipped classroom models that combine online and offline learning to maximize the learning process.

The results of this study confirm that the digital transformation of education is not only a matter of teacher ability, but also system readiness and infrastructure support. MAN 2 Tapanuli Tengah teachers are ready to change, but madrasah and education policy must be able to facilitate this change so that it can run optimally and sustainably.

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