JURNAL INOVASI

Teknologi Pendidikan

Volume 12, No 4, December 2025

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JURNAL INOVASI Teknologi Pendidikan

Volume 12, No. 4, December 2025

Volume 12, No 4, December 2025

ISSN 2407-0963 (print)
ISSN 2460-7177 (onlne)

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Ikatan Profesi Teknologi Pendidikan Indonesia & Asosiasi Program Studi Teknologi Pendidikan Indonesia
Bekerja sama dengan
Fakultas Ilmu Pendidikan dan Psikologi Univesitas Negeri Yogyakarta

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Publisher:
Ikatan Profesi Teknologi Pendidikan Indonesia (IPTPI) & Asosiasi Program Studi Teknologi Pendidikan Indonesia (APS-TPI)
in Cooperation with
Faculty of Education, Yogyakarta State University

Jurnal Inovasi Teknologi Pendidikan published in March, June, September and December

Correspondence: Faculty of Education of Yogyakarta State University
Kampus Karangmalang, Yogyakarta, 55281
Telp. (0274) 550835, Fax. (0274) 520326

Email: teknodik@uny.ac.id
Website: http://journal.uny.ac.id/index.php/jitp

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (366-382)
Online: http://journal.uny.ac.id/index.php/jitp

Analysis of the mental readiness of technology and engineering students before industrial work practice

Muliadi *, Eddy Sutadji, Isnandar, Widiyanti
Universitas Negeri Malang, Indonesia.
***** Corresponding Author. E mail: moelpuji@gmail.com

ARTICLE INFO

Article History
Received:
18 May 2025;
Revised:
5 July 2025;
Accepted:
6 July 2025;
Available online:
31 December 2025.

Keywords
Mental readiness;
Mental toughness;
Self-efficacy

ABSTRACT

Industrial Work Practice is an important stage for Vocational High School students in applying the technical skills acquired during the learning process to the world of work. Internal readiness is a determining factor for students' success in facing industry challenges. This study aims to analyse the internal readiness of students at Lingsar State Vocational High School 1, majoring in technology and engineering, before participating in pre-school, and to identify factors that affect this readiness. The method used is a quantitative descriptive method; data are collected through interviews. Moreover, questionnaires showed that 84 students had high self-confidence, while 50 felt anxious due to a lack of technical skills, and 38 admitted they lacked sufficient industry experience. A total of 95 students assessed that practitioners' roles are critical in shaping their internal readiness, indicating that educators' mentoring has a significant influence on their readiness. Statistical analysis shows that perseverance and environmental support factors contribute to students' internal readiness. Soft skill training programs, work culture simulations and strengthening psychosocial support, to ensure students have optimal internal readiness before entering the workforce.

How to cite:
Muliad et al., (2025). Analysis of the mental readiness of technology and engineering students before industrial work practice. *Jurnal Inovasi Teknologi Pendidikan, 12*(4), 366-382.
https://doi.org/10.21831/jitp.v12i4.85420

INTRODUCTION

Fieldwork practice, known locally as education and training**,** is an essential component of vocational education that aligns students' academic competencies with real-world workplace demands. By engaging directly in industry settings, vocational high school students can apply their technical skills while cultivating professional attitudes. However, studies indicate that many graduates still lack sufficient work-readiness, particularly in internal attributes such as resilience, confidence, and adaptability (Arif et al., 2023). This shortfall is compounded by structural employment challenges, including limited job opportunities, low workforce quality, and suboptimal productivity, all of which contribute to persistently high youth unemployment rates (Wahyuni et al., 2021). To address this issue, the Indonesian government enacted the Minister of Manpower Regulation No. 3 of 2017, which promotes the link-and-match initiative between vocational schools and industry. As emphasised in the regulation, private companies are expected to provide fieldwork practice opportunities for vocational high school students, as well as internships for teachers in productive subject areas (Rahmawati & Patrikha, 2022).

One of the pressing challenges in vocational education today is ensuring that graduates possess not only technical expertise but also the mental readiness and adaptive capacity required to succeed in increasingly competitive labour markets. Research indicates that many vocational high school (SMK) graduates in Indonesia continue to struggle with fundamental employability skills, including resume development, interview performance, and psychological adjustment to workplace demands (Lubis et al., 2023). This gap is exacerbated by inadequate organisational strategies and infrastructure that fail to align vocational training with real-world industry standards (Wahyuni et al., 2021). While hard skills remain essential, the development of soft skills such as communication, teamwork, and self-confidence plays a critical role in shaping graduate success (Sagirani, 2024). To address these deficiencies, fieldwork practice has been integrated as a strategic intervention, providing students with authentic exposure to workplace culture and operations, thereby easing their transition post-graduation. Vocational high schools are thus tasked not only with delivering technical instruction but also with producing graduates who are aligned with current job demands in terms of knowledge, competencies, and attitudes (Kurniawan & Mundilarno, 2023). However, despite the proliferation of SMKs in Indonesia, the persistent issue of low skill acquisition and readiness continues to hinder graduate competitiveness in the job market (Puspitasari & Bahtiar, 2022). Consequently, enhancing the relevance and responsiveness of vocational education through structured work-based learning remains a national imperative (Rahmawati & Patrikha, 2022).

Despite being positioned as a strategic source of skilled labour, graduates of vocational high schools in Indonesia consistently experience the highest unemployment rates among all education levels. According to the Central Statistics Agency, the open unemployment rate for vocational high school graduates reached 11.13% in 2021, exceeding that of general senior high school (9.09%) and even university graduates (5.98%) (Ahmad & Rachmawati, 2023; Hidayatulloh et al., 2021). This alarming trend underscores a systemic failure to prepare vocational students for real-world employment adequately. One root cause lies in the insufficient implementation of strategic educational infrastructure, including both physical facilities and career support services. Theoretically, this aligns with Human Capital Theory (Becker, 1993), which posits that investments in infrastructure, training systems, and workplace alignment directly influence the productivity and employability of graduates. Without access to modern equipment, industry-relevant learning environments, and structured guidance, students lack the contextual experience necessary to navigate job markets effectively. As Sumual et al., (2023), emphasise, work readiness is not solely the responsibility of educational institutions but requires multisector collaboration. Furthermore, Rohman et al., (2022), define work readiness as a comprehensive state encompassing physical, mental, and psychological preparedness attributes that cannot be developed in environments lacking adaptive learning tools. Preparing graduates for Industry 4.0 demands infrastructure that goes beyond classrooms; it requires a robust ecosystem of mentoring, simulation-based training, and industry integration to foster the core capabilities described by (McDonald & Paganelli, 2021).

Work readiness encompasses a combination of skills, knowledge, and personal attributes that enable individuals, particularly vocational high school students, to transition effectively into the labour market (Togher et al., 2023). Beyond technical competencies, readiness also involves understanding workplace dynamics and developing soft skills such as communication, problem-solving, emotional regulation, and teamwork, which are increasingly regarded as critical for long-term career success (Sagirani, 2024; Sumual et al., 2023). Vocational education aims to produce graduates who are not only skilled but also mentally prepared to enter complex and evolving work environments (Jafri et al., 2024; Elfranata et al., 2023). However, studies reveal that many students possess adequate hard skills but still lack psychological resilience and adaptability, contributing to high dropout rates and difficulty sustaining employment (Susanti. Factors such as self-concept, self-efficacy, and emotional maturity significantly influence one's ability to persevere and perform under pressure (Esa et al., 2022; Itryah & Anggraini, 2022). Muna et al. (2022) emphasise that students who can make independent career choices based on interest and motivation are more likely to develop a sense of purpose and long-term work engagement. Conversely, those with low self-esteem often experience internal stress, including test anxiety, which undermines their readiness to face real-world challenges (Rahmawati et al., 2021). Therefore, strengthening soft skills and psychological resilience must be prioritised alongside vocational training to ensure graduates are truly workforce-ready, not

just technically capable, but mentally and socially equipped for success (Sari & Mariyanti, 2024; Miftahuddin & Robani, 2023).

Mental readiness in making career decisions encompasses affective, cognitive, and psychomotor aspects, collectively forming individuals' psychological readiness to enter the workforce (Hidayati, 2023). The affective aspect relates to the ability to manage emotions and motivation; the cognitive aspect refers to critical thinking and decision-making skills; while the psychomotor aspect reflects the readiness to carry out actions effectively in a work context. Work readiness is not merely about technical ability, but also heavily influenced by internal readiness, an individual's psychological and physical capacity to perform tasks efficiently (Hidayati, 2023). This internal readiness serves as foundational capital, enabling individuals to achieve optimal career outcomes. One key factor influencing internal readiness is adaptability, especially in responding to dynamic work environments. This adaptability is cognitively represented by the concept of career rigidity, which describes an individual's resistance to change or career flexibility (Lasut et al., 2024). High levels of career rigidity may hinder psychological readiness by limiting one's ability to adjust to shifting job demands. Furthermore, work readiness is described as a state of harmony among physical, internal, and existential maturity that enables individuals to perform work-related activities effectively (Riyanti & Kasyadi, 2021). However, this ideal condition is increasingly challenged by the rising mental health crisis among adolescents and young adults, which is becoming a significant global concern. Reports indicate that mental health issues are escalating, affecting young people's ability to cope with transitions, including entry into the labour market (Rahmahdiyyah & Pujianto, 2024). Therefore, psychological readiness must be considered a central component of the school-to-work transition process, requiring targeted interventions through career guidance, soft skills development, and continuous psychosocial support to prepare students for modern work environments.

Work readiness is deeply influenced by various internal factors, particularly self-regard, which shapes how adolescents perceive their abilities and interact with their social environment. Positive self-evaluation reinforces motivation and confidence, both of which are critical for navigating workplace challenges (Elfranata et al., 2023). Key components that determine internal readiness include prior experiences, psychological maturity, logical reasoning, emotional regulation, and the ability to collaborate and adapt in dynamic work environments (Susanti et al., 2024). In this context, self-efficacy plays a pivotal role. Students who believe in their capacity to succeed are more resilient and engaged during transitions such as internships or entry-level employment. External factors also contribute, including academic performance, parental support, social and career guidance, and hands-on experiences through industrial work practices (Riyanti & Kasyadi, 2021). The absence of psychological preparedness, marked by low self-confidence and poor stress management, can lead to failure to thrive during field placements or professional induction. Therefore, assessing students' internal readiness before fieldwork is crucial to ensuring successful adaptation. Future studies are needed to explore further the interplay among work readiness, vocational competence, and psychological constructs such as motivation and self-efficacy (Ismoyo & Wahjudi, 2023).

This study examines the internal readiness of engineering technology scholars before externship and the factors that impact it. The thing is to describe scholars' internal readiness before externship. Dissect the internal and external factors that impact their readiness before externship, which will eventually serve as the foundation for entering the world of work. The benefits of this study are anticipated to provide seminarians with an overview of how to design internal medication programs before externship, so that their expectations are met. Provide input to the artificial world to foster externship actors.

The novelty of this research lies in the mental readiness of Vocational High School students majoring in Technology and Engineering before participating in industrial work practices. This aspect has rarely been explored comprehensively in previous studies that have focused more on post-internship job readiness or on technical skills alone. This study offers an integrative approach by combining psychological instruments, such as the Big Five Personality Test, Grit Scale, and Self-Efficacy Test, thereby providing a more holistic picture of student readiness. In addition, this study identified in detail the sources of students' anxiety, especially a lack of technical skills and industry experience, which are the dominant factors inhibiting internal readiness. An important contribution

of this research is in the practical realm and vocational education policy, namely by recommending the integration of soft skills training, work culture simulation, and strengthening psychosocial support into the curriculum design of vocational high schools. This study provides a strong conceptual and practical foundation for developing a more comprehensive mental-readiness-based vocational education model.

METHOD

This study employed a quantitative descriptive approach to assess vocational students' internal work readiness prior to their fieldwork practice. The study involved 86 eleventh-grade students majoring in Engineering Technology at Vocational High School, Students 1 Lingsar, who were preparing for an externship. The total sampling technique was applied, in which the entire population was involved as respondents. This method was selected because the population size was both manageable and homogeneous, allowing researchers to obtain comprehensive data without introducing sampling error or generalisation bias. Data collection was conducted through a Likert-scale questionnaire assessing components of self-confidence, stress management, social adaptation, and work motivation. To enrich the psychological dimension, standardized instruments were employed: the Big Five Personality Test, which measures Neuroticism, Extraversion, Openness, Agreeableness, and Conscientiousness (McDonald & Paganelli, 2021); the Grit Scale to evaluate perseverance toward long term goals; and a self efficacy Test to examine students' perceived ability to tackle work challenges (Itryah & Anggraini, 2022; Esa et al., 2022). The study also examined external factors, including the roles of teachers and schools in providing career guidance, family and peer support, prior externship experiences, and industry expectations (Sumual et al., 2023).

The primary instrument included adaptations of the Work Readiness Index (Brady, 2010) and the Emotional Quotient Index (EQI), grounded in Goleman's framework, as adapted by Chikobvu & Harunavamwe (2020). As explained by Ningsih et al., (2021), quantitative research emphasises data collection through measurement instruments and analysis using statistical procedures. The questionnaire was administered offline and analysed using SPSS version 23, involving descriptive statistics (mean, standard deviation, frequency, and percentage) and Pearson's product-moment correlation analysis for hypothesis testing (Ningsih et al., 2021). Instrument reliability was examined using Cronbach's Alpha, with a threshold of >0.70 indicating internal consistency (Wahyuni et al., 2021). The study employed an explanatory quantitative design to identify and analyse the relationships among Soft Skills (X_1), Hard Skills (X_2), and Work Readiness (Y) (Susanti Siregar et al., 2024). This framework enabled a comprehensive understanding of both internal psychological factors and the instructional and experiential components that influence student preparedness.

Based on the results of the reliability test using Cronbach's Alpha, a value of $\alpha = 0.936$ was obtained from 19 instrument items. This value indicates a very high level of internal consistency, exceeding the commonly accepted threshold of 0.70 in social science research. After standardisation, Cronbach's Alpha increased slightly to 0.939, confirming that internal consistency was maintained and even improved. These results indicate that the instrument items are strongly consistent in measuring the intended constructs. Therefore, the research instrument demonstrates excellent reliability and can be used with confidence to measure the variables under study with high accuracy.

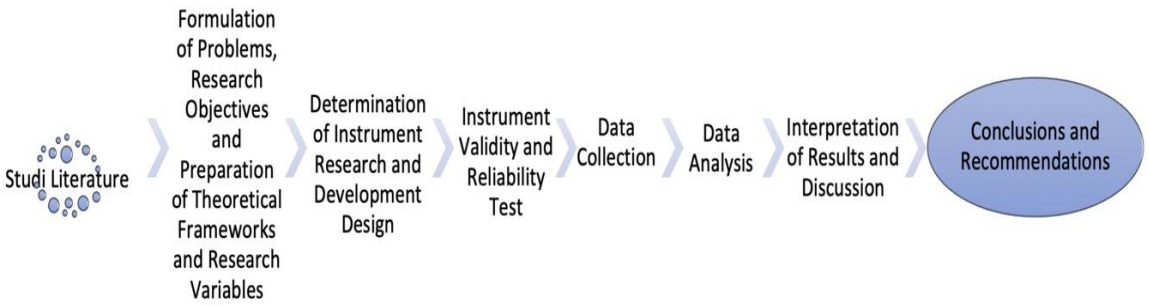

Figure 1. Flow Chart Research Method

The questionnaire items were developed to operationalise the conceptual framework of students' work-readiness into measurable indicators. Each item represents specific psychological and behavioural constructs related to internal work readiness, including self-efficacy, resilience (grit), emotional readiness, discipline and responsibility, and adaptability. These constructs were selected based on established theories of work readiness and personality development and aligned to assess students' preparedness for industrial work practice. The instrument employed a five-point Likert scale ranging from strongly disagree to agree strongly. A detailed description of the research instrument is presented in Table 1.

Table 1. Research Instrument

No.	Indicator	Aspects/Constructs	Instrument Statement	Likert Scale
1	Confidence in completing industrial tasks	Self efficacy	I am confident I can complete the assigned work tasks during industrial practice.	1 – 5
2	Ability to cope with job challenges	Self efficacy	I feel capable of facing the challenges that will arise in the workplace.	1 – 5
3	Resilience in the face of failure	Resilience (grit)	I kept trying even though I had experienced several failures.	1 – 5
4	Commitment to long-term goals	Resilience (grit)	I am committed to pursuing my long-term career goals.	1 – 5
5	Managing emotions while working in a new environment	Emotional readiness	I can manage my emotions in a new, unfamiliar work environment.	1 – 5
6	Confidence in new situations	Emotional readiness	I am confident in facing new situations during practice	1 – 5
7	Responsibility for completing tasks	Discipline and Responsibility	I always complete my tasks on time without being reminded.	1 – 5
8	Rigour in work	Discipline and Responsibility	I always pay attention to detail in every task I do.	1 – 5
9	Willingness to keep learning	Adaptability	I am open to new experiences and willing to learn new things in the world of work.	1 – 5
10	Response to criticism or evaluation	Adaptability	I received criticism as input to improve my performance.	1 – 5

RESULTS AND DISCUSSION

Results

The data collected based on the questionnaire was analysed with the results in Figure 2 as follows:

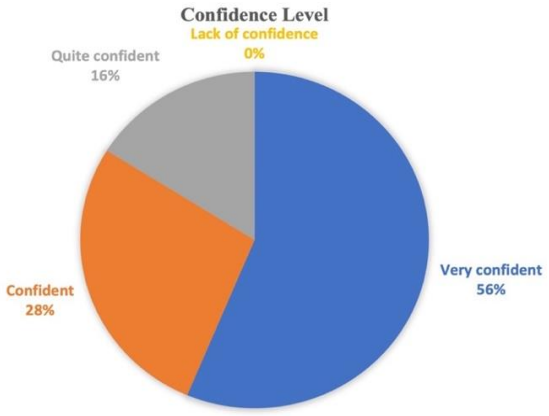

Figure 2. Test Results Student Confidence Level

Data show that students' self-confidence is powerful 84% report feeling either confident or very confident, and none express any lack of confidence. A total of 56 students stated they were very confident, while 28 felt confident, placing the majority firmly in the positive confidence category. Even the remaining 16 students reported being quite confident, suggesting that all students possess at least a moderate sense of self-assurance. These findings reflect an educational environment and student experiences that appear to foster confidence. Theoretically, this aligns with Bandura's Self-Efficacy Theory (1997), which posits that individuals' beliefs in their capabilities significantly influence their behaviour, perseverance, and success when facing challenges. In the context of work readiness, self-efficacy is a central indicator of mental preparedness: students who believe in their competence are more likely to remain resilient under pressure, adapt quickly, and stay motivated to grow. Bandura identifies key sources of self-efficacy: vicarious experience, verbal persuasion, and mastery experience, all of which can be traced in students' learning environments and pre-employment exposure. Therefore, high self-confidence is not only a psychological asset but also an objective indicator of vocational students' mental readiness to enter the workforce. This is supported by findings from Talitha & Novi (2024), which suggest that industrial work practices, access to labour market information, and the socioeconomic background of students' families partially influence their level of work readiness. Investing in confidence-building through structured learning and workplace exposure thus plays a critical role in preparing students to meet professional challenges with assurance and adaptability.

Locus of control positively influences the work readiness of mechanical engineering scholars (Hidayatulloh et al., 2021), with artificial work practices exerting a positive and significant influence on scholars' work readiness. Scholars' work-readiness is in the ready order, with a chance position of 75.91 per cent (Ashdown et al., 2023). This is supported by 7 pointers which include having logical and objective considerations, having the capability and amenability to work with others, being suitable to control oneself or feelings, having a critical station, having the courage to accept responsibility collectively, having the capability to acclimatize to the terrain and technological developments, having the ambition to advance and trying to follow developments in the field of moxie (Hidayati, 2023). There are influences of self-esteem and self-efficacy on scholars' work readiness, and of tone regard and tone regard together on scholars' work readiness (Elfranata et al., 2023). Social support and parental self-regulation have implications for the development of learning independence (Yulianingsih & Fathiyah, 2025).

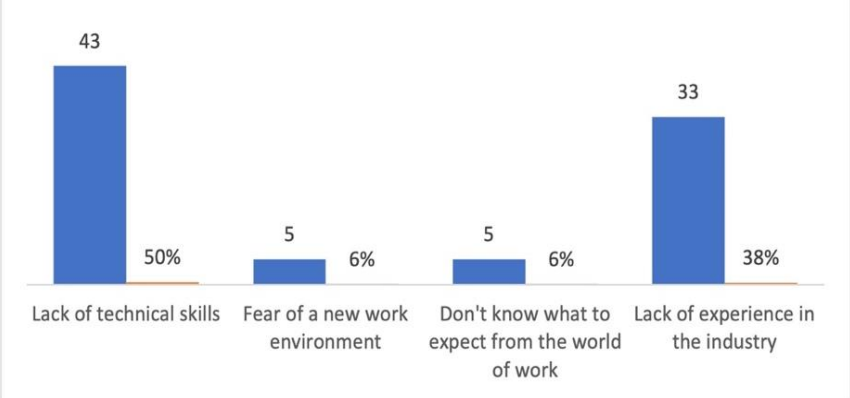

Figure 3. Graph Student Anxiety Level

Figure 3 shows that the main factor contributing to students' anxiety before entering the workforce is the lack of technical skills, affecting 50% of students. Additionally, 38% of students report a lack of industry experience, indicating that more than a third feel they lack sufficient work experience. Furthermore, 6% of students reported feeling anxious due to fear of the new work environment or uncertainty about what to expect in the workforce. These findings confirm that students' anxiety relates more to practical competency and authentic experiences rather than psychological or emotional factors. Educational institutions are expected to enhance practice-based

learning, such as technical training and internship programs, to prepare graduates better to enter the workforce with greater confidence and competence.

Anxiety affects job readiness. This study found that anxiety does not necessarily affect job readiness, task concentration, or the ability to form effective opinions (Togher et al., 2023). Anxiety also leads to inordinate solicitude about the judgment of others and the outgrowth of job readiness. Anxiety can lead to physical and internal prostration due to the need to keep allowing, performing, or a drop in energy or interest in preparing for work. Depression rates among recent graduates have a significant negative impact on their capability to demonstrate job readiness. Lack of tone provocation and incapability to form opinions and progress in their careers (Rahmahdiyyah & Pujianto, 2024). Emotional intelligence is a factor that affects job readiness (Miftahuddin & Muhammad, 2023).

The variable that most affects scholars' job readiness is artificial work practice, with a beta value of 0.477. The significance of practical experience in shaping the work readiness of vocational academy scholars (Sari & Mariyanti, 2024). The internal health of recent graduates in the study of job readiness is associated with better adaptation to the new work terrain, increased productivity, and advanced job satisfaction (Verbeek et al., 2022). Factors similar to social support, adaptability, and the capacity to manage depression, anxiety, stress, and religiosity can affect internal health and job readiness (Rahmahdiyyah & Pujianto, 2024).

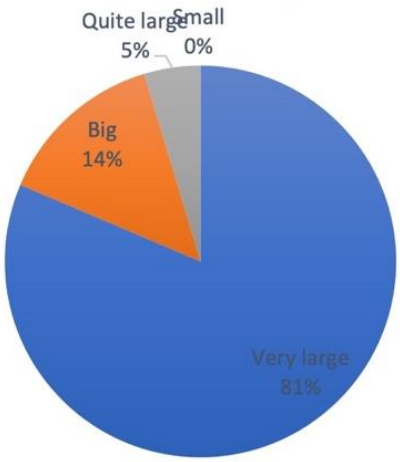

Figure 4. Graph of the Teacher's Role in the Mental Preparation of Students

Figure 4 explains the importance of teachers as mentors and motivators in students' mental development and emotional readiness. As many as 95% of students consider the role of teachers to be vital; educational institutions should continue to strengthen teachers' roles, not only as teachers but also as coaches of students' character and mentality. In Graph 3 above, the majority of students (81%) consider the role of teachers to be very important in helping students mentally prepare for the world of work. As many as 14% of students stated that the role of teachers is relatively significant, and the other 5% consider it quite large.

These findings support the view that preceptors not only deliver literacy accoutrements but also serve as facilitators of scholars' cognitive and motivational development. The role of preceptors in education should be expanded to include character development, internal readiness, and the formation of a positive attitude towards future challenges. The impact on children's intelligence can be the family environment or maternal parenthood. The child's academic readiness is determined by three factors: maternal parenthood, maternal education position, and children's social status. Their parental style and educational background influence children's social gestures (Mutiah et al., 2025). Strategy to strengthen internal readiness, organising a soft chops training program before Industrial Work Practices. Provide a simulation of an artificial work culture through mini-systems or case studies (Ashdown Franks et al., 2023). Adding collaboration with the artificial world in furnishing debriefing on the world of work (Cristiano et al., 2021).

Table 2. Statistical Factors that Support Discipline and Responsibility Attitudes

Discipline and Responsibility	N	Sum	Mean	Std. Error	Std. Deviation
Always complete tasks on time	86	347	4.03	.061	.563
Very attention to detail in my work	86	357	4.15	.065	.604
Doing the best in every job	86	369	4.29	.068	.630
Have full responsibility for the task	85	368	4.33	.061	.565
Valid N (listwise)	85				

Table 2 describes students' attitudes toward discipline and responsibility in their work behaviour. The results indicate that most students demonstrate a high level of discipline and responsibility in completing their tasks. The variable always completing tasks on time shows a mean score of 4.03 with a standard deviation of 0.563, indicating a relatively consistent habit of timely task completion among students. The variable paying close attention to detail in work has a mean of 4.15 and a standard deviation of 0.604, suggesting that students generally maintain strong attention to detail. The variable performing best across all job records has a mean score of 4.29 and a standard deviation of 0.630, reflecting students' strong effort to perform optimally. Meanwhile, the variable having full responsibility for the task achieves the highest mean score of 4.33 with a standard deviation of 0.565, indicating that students most consistently demonstrate responsibility compared to the other aspects.

Table 3. Factors that Support Perseverance and Persistence

Persistence and persistence factors (resilience scale)	N	Sum	Mean	Std. Error	Std. Deviation
Strive to achieve goals despite many failures	86	359	4.17	.071	.654
It is not easy to give up on difficult tasks	86	352	4.09	.059	.545
Commit to long-term goals	86	352	4.09	.051	.476
Often looking for other ways to solve problems when encountering obstacles	86	365	4.24	.068	.631
Believes that hard work is the key to success	86	370	4.30	.070	.652
Do not be tempted to abandon your goal even though there are other, easier options	86	353	4.10	.066	.614
Can maintain self-motivation to achieve career goals	85	351	4.13	.062	.573
Valid N (listwise)	85				

According to Table 3, the majority of students demonstrate a high level of perseverance and persistence in achieving their goals. The variable "Strive to achieve goals" has an average score of 4.17 with a standard deviation of 0.654, indicating that most students maintain a high level of effort even when facing obstacles. The variable "It is not easy to give up on complex tasks" has an average of 4.09 and a standard deviation of 0.545, indicating that students generally exhibit resilience when confronted with challenges. The variable Commit to long-term goals also has an average of 4.09 with a standard deviation of 0.476, reflecting a relatively uniform commitment among students.

The variable, often looking for other ways to solve problems when encountering obstacles, has an average of 4.24 with a standard deviation of 0.631, indicating that students tend to seek alternative solutions when facing difficulties. The variable "Believes that hard work is the key to success" had the highest average of 4.30 and a standard deviation of 0.652, highlighting that students strongly value effort as a pathway to achievement. The variable "Do not be tempted to abandon your goal even though there are other, easier options" has an average of 4.10 and a standard deviation of 0.614, suggesting that students resist shortcuts and remain focused on their objectives. Finally, the variable 'Can maintain self-motivation to achieve career goals' has an average of 4.13 and a standard deviation of 0.573, indicating that students generally sustain motivation toward their career ambitions. Overall, these results demonstrate that students possess high levels of resilience, persistence, and intrinsic motivation, which are essential for achieving long-term success.

Table 4. Factors of Students' Efficacy Attitudes

Students' confidence in self-efficacy	N	Sum	Mean	Std. Error	Std. Deviation
Confident in being able to complete tasks in the world of work	86	351	4.08	.053	.490
Be able to handle work challenges with confidence	86	349	4.06	.048	.443
Able to make the right decision	86	339	3.94	.051	.469
Can work independently without much direction	86	324	3.77	.085	.792
It is not easy to hesitate in taking steps to get the job done	86	339	3.94	.065	.601
Can learn new skills quickly if needed	86	346	4.02	.062	.573
Able to find solutions when facing problems at work	86	352	4.09	.059	.545
Confident in overcoming difficulties in a new work environment	86	341	3.97	.053	.496
Valid N (listwise)	86				

Based on Table 4, students generally demonstrate a high level of self-efficacy in facing work-related challenges. The variable "Confident in being able to complete tasks in the world of work" has a mean of 4.08 and a standard deviation of 0.490, indicating that most students feel capable of performing their tasks effectively. The variable "Be able to handle work challenges with confidence" has a mean of 4.06 and a standard deviation of 0.443, indicating strong confidence in overcoming work-related difficulties. Able to make the right decision has a mean of 3.94 and a standard deviation of 0.469, suggesting that students are generally confident in their decision-making and exhibit relatively low variation. The variable Can work independently " obtained a mean of 3.77 and a higher standard deviation of 0.792, indicating more variability in students' ability to work independently. It is not easy to hesitate in taking steps to get the job done, with a mean of 3.94 and a standard deviation of 0.601, showing students tend to act decisively when completing tasks. The variable "Can learn new skills quickly if needed" has a mean of 4.02 and a standard deviation of 0.573, indicating good adaptability in acquiring new skills. Able to find solutions when facing problems at work has the highest mean of 4.09 with a standard deviation of 0.545, suggesting students are confident in problem-solving. Finally, Confidence in overcoming difficulties in a new work environment has a mean of 3.97 and a standard deviation of 0.496, indicating that students generally feel able to adapt to new work contexts. Overall, the results indicate that students' self-efficacy is relatively high, particularly in adaptability, problem-solving, and learning new skills, although only 41.3% fall into the 'high' self-efficacy category (Setyawan, 2019).

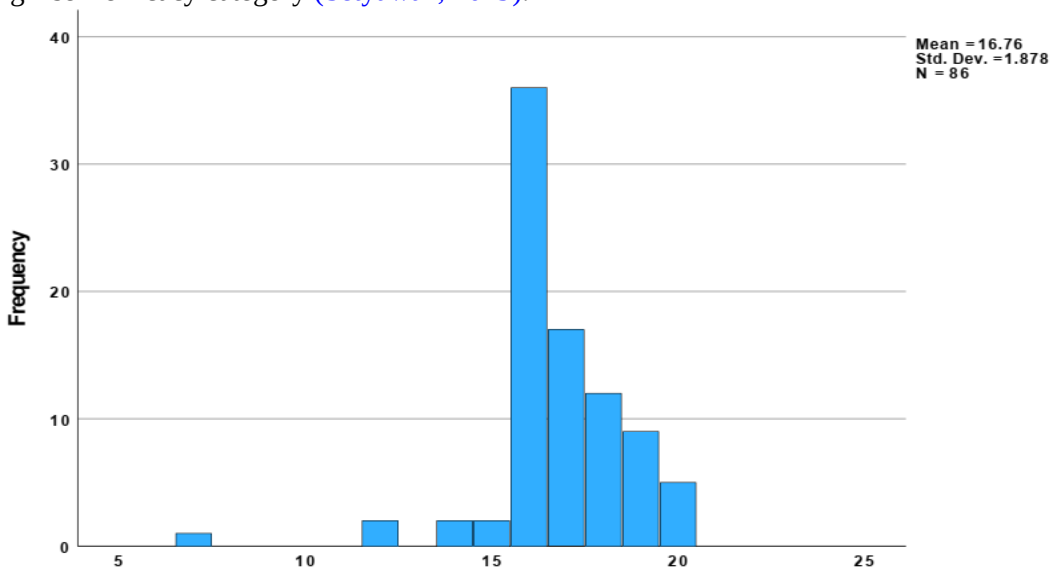

Figure 5. Score Graph of Student Discipline Attitude and Responsibility

Based on Figure 5, the frequency distribution shows the pattern of data for the caution variable, which includes aspects of discipline and pupil responsibility in completing tasks. The average score on this variable was 16.76, with a standard deviation of 1.878, indicating that scholars' maturity is at a reasonably high level of discipline and responsibility and is relatively invariant. The frequency distribution shows that most scholars have scores between 15 and 20, indicating that their caution is relatively high. Some individuals have lower scores below 10, reflecting variations in the position of discipline and responsibility. The graph also shows that the distribution of data tends to be centred around average scores, which can be interpreted as the maturity of scholars having harmonious patterns of geste in terms of caution.

The relatively slight standard deviation (1.878) indicates that the data are not very dispersed, suggesting that most scholars have fairly consistent character in terms of discipline and responsibility. These results show that scholars' prudence in the environment of discipline and responsibility is at a pretty good position. The results of the exploration analysis show that the average position of scholars' work-readiness scores is in the low range (33), indicating that they are not ready to enter the world of work and contend in the encyclopedic domain (Jafri et al., 2024). The donation of learning achievement, K3 knowledge, and practical experience together to job readiness is 21.5. The Industrial Work Practices experience is vitally important for supporting scholars' work-readiness, as it offers numerous benefits (Puspitasari & Bahtiar, 2022).

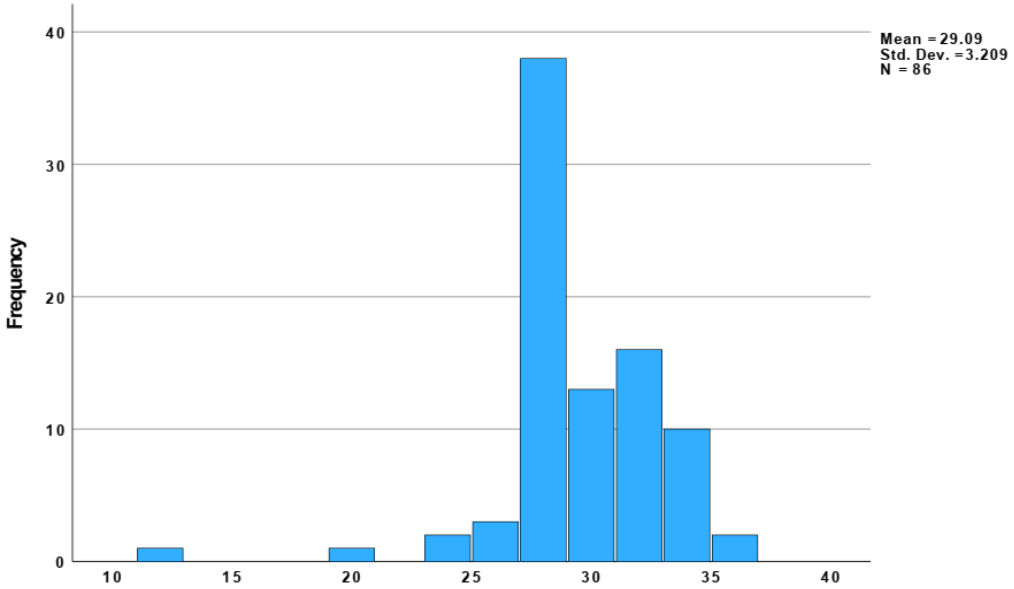

Figure 6. Student Toughness Scale Score Graph

Based on Figure 6, the frequency distribution shows that students' perseverance and persistence in facing academic challenges are relatively high. The graph shows the data distribution, with a mean of 29.09 and a standard deviation of 3.209, indicating that the majority of students have scores in a relatively centralised range around the average. Visually, the graph shows a near-normal distribution, with the highest frequency between 25 and 35, indicating that most students have a stable level of resilience in completing assignments and overcoming academic obstacles. Few individuals have a score below 20, which suggests that a small percentage of students may have difficulty maintaining perseverance and persistence in the learning process. The distribution of the data also showed that the variation in scores was not very large, as indicated by the relatively small standard deviation (3.209). This indicates that students have a fairly uniform pattern of resilience, with little difference between individuals in terms of academic fighting power. These results suggest that the majority of students exhibit strong perseverance and high resilience in the face of educational challenges, with a small percentage requiring additional interventions to improve their resilience. Students must have high motivation to achieve the desired goals (Miftahuddin & Muhmmad, 2023).

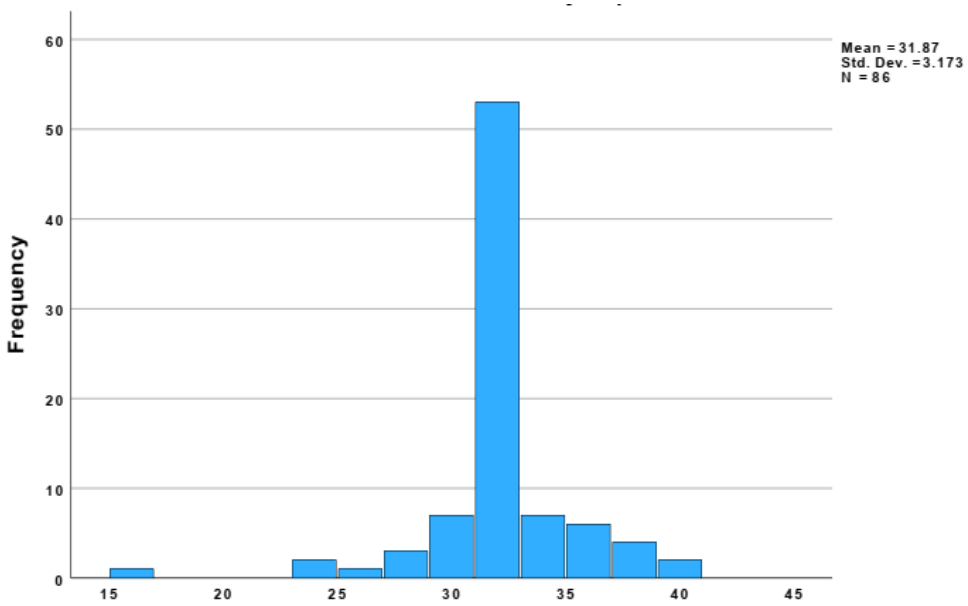

Figure 7. Students′ Self-Efficacy Attitude Scores

Based on Figure 7, the frequency distribution shows the pattern of students' confidence in their abilities (Self-efficacy). From the analysis, the mean (Mean) was 31.87, the standard deviation (Std. Dev) was 3.173, and the sample size (N) was 86. The distribution graph indicates that most learners have moderate to high self-confidence, with peak frequencies between 30 and 35. This aligns with findings that show students generally exhibit strong self-efficacy, reflecting confidence in facing academic tasks and completing assignments effectively. Self-efficacy, as conceptualised by Bandura (1997), is not an isolated trait but is closely intertwined with the teaching approaches students experience. Instructional methods that foster autonomy, intrinsic motivation, and learner ownership, such as project-based learning, guided inquiry, and differentiated instruction, are shown to enhance students' belief in their capabilities, thus reinforcing both academic and vocational readiness.

In vocational settings, learning experiences that simulate real-world applications, such as artificial work practices, not only develop domain-specific skills but also cultivate adaptive behaviours and professional confidence (Surya et al., 2023). Educators play a pivotal role in shaping these outcomes as highlighted by Dewi et al., (2024), the role of instructors (often serving as industry facilitators or tutoring manufacturers) significantly influences students' preparation for the workforce This implies that instructional design should go beyond the delivery of content and actively integrate practices that stimulate student autonomy, mastery experiences, and goal setting all core contributors to self efficacy. Moreover, studies emphasise the synergistic impact of work-based learning and students' interests on job readiness (Wahyuni et al., 2021), underscoring the need for responsive pedagogical frameworks. These frameworks must balance structured guidance with opportunities for self-directed exploration, enabling students to internalise their learning journey and emerge not only competent but mentally prepared to meet workplace expectations. Highlight the importance of self-awareness and self-confidence in improving learning outcomes by increasing academic motivation. This research contributes to the theoretical understanding of the psychological factors that influence learning achievement and has practical implications for the development of educational interventions (Kurniasih et al., 2025).

Table 5. CPS Test Results

		N	%
Cases	Valid	84	97.7
	Exclude[a]	2	2.3
	Total	**86**	**100.0**

a. Listwise deletion based on all variables in the procedure

Based on Table 5 of the Case Processing Summary test results, as many as 97.7% of the data were considered valid for analysis. In comparison, 2.3% of the data were excluded due to noncompliance with the processing criteria (listwise deletion). The data used in the study were highly complete, with only a small amount excluded. Listwise deletion means that if a variable is missing for a case, the entire case is removed from the analysis, leaving only fully complete cases for further analysis. The total number of samples is 86 students; the high data validity (97.7%) ensures that statistical analysis can be carried out with optimal accuracy. However, there are 2 deletions, which may be concerning if the amount of deleted data increases in other analyses.

Discussion

The development of vocational students' work-readiness is shaped by a constellation of interconnected psychological, instructional, and environmental factors, most notably self-efficacy, emotional intelligence, anxiety regulation, and resilience. Research indicates that structured career guidance and counselling programs account for approximately 32.26% of the variance in work readiness among vocational high school students (Arif et al., 2023). These programs enhance students' occupational orientation while fostering career maturity. At the individual level, self-efficacy consistently emerges as a critical psychological predictor, encouraging students to believe in their ability to succeed, take ownership of their learning, and remain persistent in the face of academic or technical challenges (Itryah & Anggraini, 2022; Puspitasari & Bahtiar, 2022). The current study's Cronbach's Alpha score of 0.936 further confirms high internal consistency in assessing the discipline, responsibility, and intrinsic motivation character traits, which are essential to entrepreneurial initiative and adaptability in dynamic work environments (Sulaiman et al., 2022).

Despite these promising insights, vocational students' readiness is not evenly distributed across populations. While many demonstrate high levels of self-efficacy, others remain vulnerable, particularly those struggling with stress management and lacking autonomy in career-related decision-making, as is often noted among female students (Hidayati, 2023). Emotional intelligence (EI) plays a vital role in this regard. Components such as self-awareness, self-regulation, empathy, and social motivation equip students to navigate interpersonal dynamics, mitigate performance anxiety, and maintain composure under pressure. Students with higher EI tend to transition more smoothly into new workplace settings, forming productive networks and sustaining professional relationships that contribute to long-term employability (Ocampo et al., 2022; Miftahuddin & Robani, 2023).

Psychological resilience and mental readiness are indispensable for maintaining productivity under real-world demands. Students exposed to authentic industrial work practices who also demonstrate high self-efficacy exhibit significantly better job-readiness outcomes, accounting for as much as 46.4% of the variance in some cases (Neswari & Dwijayanti, 2022). Resilience empowers learners to recover from setbacks and persist through uncertainty, while anxiety regulation supports task focus and performance stability. These soft traits are often developed through iterative exposure to challenges and responsibilities, including internships and school-industry collaborations. Meanwhile, psychological constructs such as internal locus of control and future time orientation are positively associated with self-directed career planning, thereby strengthening the ability to forecast, strategise, and invest in long-term goals (Muna et al., 2022).

Several hindrances continue to undermine students' full potential. Emotional dysregulation, such as excessive self-doubt or avoidance behaviours, can erode confidence and delay progress. Additionally, overreliance on parents or guardians for career direction diminishes autonomy, especially in contexts where cultural norms may prioritise obedience over initiative (Hidayati, 2023; Yalcin et al., 2021). Interventions should therefore adopt a holistic approach that combines psychosocial support, practical experience, and scaffolded decision-making skills. By empowering students with both technical competency and psychological flexibility, vocational institutions can foster work-ready graduates who are not only skilled but also self-aware, future-focused, and resilient in navigating the evolving demands of the labour market.

CONCLUSION

Based on the findings, it can be concluded that students of Vocational High School Students 1 Lingsar majoring in Engineering Technology exhibit a generally high level of mental readiness, particularly in confidence, perseverance, and self-efficacy, which are essential for preparing them for industrial work placements. Most students show strong internal psychological assets, with high average scores in grit and self-efficacy, indicating their capacity to face academic and career challenges effectively. Teacher support and school guidance play a significant role in fostering this readiness, although limitations in technical skills and prior industry exposure remain challenges for some students. These results suggest the need for vocational education to integrate practice-oriented instructional models, such as immersive internship experiences, workplace simulations, and project-based assignments, to strengthen both technical competence and mental preparedness. Furthermore, schools should implement dedicated soft skills modules focusing on persistence, emotional regulation, and goal-setting strategies, complemented by personalised mentoring programs to support students with lower self-efficacy. At the policy level, mental readiness indicators should be included alongside cognitive and technical assessments to ensure a holistic approach to student development. By systematically embedding these strategies, vocational education can move beyond skill delivery to cultivate graduates who are adaptive, resilient, and workforce-ready.

ACKNOWLEDGEMENT

Thank you to the supervisors, technical staff, and administrative staff who have provided direction, technical assistance, and support during the research process. Thank you to The Indonesian Education Scholarship Program, Center for Higher Education Funding and Assessment (PPAPT) and the Indonesian Education Endowment Fund of the Ministry of Hinger Education, Science, and Technology of Republic Indonesia for supporting funding for the author, so that the author's article is suitable for publication in Journal Educational Technology Innovation.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (383-400)
Online: http://journal.uny.ac.id/index.php/jitp

Articulate Storyline chemistry learning with socio-scientific issues to enhance students' critical thinking

Siti Khadijah [1], Arif Sholahuddin[1]*, Miranda Nora'in [1], Norsifa Humaira [1], Febry Rosita [1], Muhammad Ismi Rezani [2]
[1] Universitas Lambung Mangkurat, Indonesia.
[2] SMAN 6 Banjarmasin, Indonesia.
* Corresponding Author. E-mail: arif.science.edu@ulm.ac.id

ARTICLE INFO

Article History
Received:
18 July 2025;
Revised:
4 October 2025;
Accepted:
5 October 2025;
Available online:
31 December 2025.

Keywords
Articulate Storyline;
Chemical bonding;
Critical thinking;
Interactive learning media S;ocio-scientific issues

ABSTRACT

Critical thinking is essential for students' academic and life success, yet many students perform poorly because instructional approaches often fail to promote higher-order thinking. This study developed an interactive learning medium that integrates Socio-Scientific Issues (SSI) using Articulate Storyline and evaluated its validity, practicality, and effectiveness in improving students' critical thinking about chemical bonding. The research employed a Research and Development (R&D) design based on the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). Participants were 67 eleventh-grade students (34 from XI-1 and 33 from XI-4), aged 15–16 years. Data were collected using validation sheets, questionnaires, observation sheets, and pretest–posttest critical thinking tests. Results showed the media was valid (content validity index = 0.97), highly practical (mean practicality score = 4.33), and effective (mean N-gain = 0.77), indicating substantial improvement in students' critical thinking. The study concludes that SSI-based interactive materials developed with Articulate Storyline are feasible and effective for teaching chemical bonding; theoretically, the findings support the role of SSI and digital interactive media in fostering higher-order thinking, and practically, teachers are recommended to adopt these materials to enhance critical-thinking instruction.

How to cite:
Khadijah et al., (2025). Articulate Storyline chemistry learning with socio-scientific issues to enhance students' critical thinking. *Jurnal Inovasi Teknologi Pendidikan. 12*(4), 383-400.
https://doi.org/10.21831/jitp.v12i4.88558

INTRODUCTION

Critical thinking can be defined as the ability to draw logical conclusions from existing evidence, engage in rational thinking, and maintain intellectual honesty (Santyasa et al., 2021). Critical thinking skills are essential for everyone to have, because through critical thinking skills, everyone can think logically, be able to interpret information, make decisions and the right choices based on the data obtained and conduct analysis in various areas (Safarati & Zuhra, 2023; Sudiarti et al., 2023; Zuhra & Arifiyanti, 2021). Students' critical thinking skills are suboptimal because school learning still lacks activities to hone them (Agnafia, 2019).

Cooperation and interaction between teachers and students are needed to support the improvement of students' critical thinking skills (Ramadhanti & Agustini, 2021). In addition,

teachers must integrate learning media, learning processes, and assessment methods to train essential thinking skills (Yulianti et al., 2022). PowerPoint (PPT) is a learning medium often used (Susilawati et al., 2021). Although often used, learning media such as PPTs have several limitations. A lecture-based approach can reduce students' active involvement in the learning process, as they tend to receive information passively without meaningful interaction, leading to boredom (Trisantri et al., 2024). This limited interaction also contributes to the underdevelopment of students' critical thinking skills (Baker et al., 2018).

Learning media suitable for the current era is interactive, engaging learners through images, colours, text menus, animations, videos, audio, and quizzes. Learners can directly use and interact with the material being studied (Safira et al., 2021). This approach aims to create a more memorable learning experience, make it easier for students to understand the material, encourage them to be more active, and enhance the effectiveness of the classroom learning process (Inayah et al., 2023). One learning medium that can improve critical thinking skills is interactive learning media (Blyznyuk & Kachak, 2024; Dermawan et al., 2025; Febliza et al., 2023). The use of interactive learning media is considered necessary in the learning process because it can create broader and deeper interactions (Mustika et al., 2018). Interactive media is an innovation on previous learning media; it combines text, sound, images, and video in a single digital format (Jazuli et al., 2017).

The software used to create interactive learning media is Articulate Storyline. It is a software that functions as a presentation and communication tool. This application allows users to start with available templates and customise the characters according to their preferences (Wahyuni et al., 2022). Articulate Storyline also has features for adding audio, video, animation, quizzes, and assessments (Sukmarini et al., 2021).

Various studies have developed Articulate Storyline-based learning media used across fields such as biology, chemistry, and others (Daryanes et al., 2023). In chemistry, this media is used to support learning, both in class and in independent learning at home. For example, on chemical bonding materials, Articulate Storyline media is designed using videos, images, interactive characters, and evaluation questions to improve student understanding (Lestarani et al., 2023). In addition, similar media have been developed for atomic structure and the periodic table of elements, which can help students interact actively and assist them in understanding concepts through visualisation and demonstrations of materials (Lestarani et al., 2023).

Although previous studies have demonstrated that the use of Articulate Storyline (AS) is effective in enhancing student engagement, visualisation, and conceptual understanding, most have primarily emphasised its technological aspects, such as animations, videos, and interactive features. On the other hand, research on Socio-Scientific Issues (SSI) highlights the importance of incorporating real, controversial, and socially relevant issues to foster critical thinking and evidence-based decision-making. Nevertheless, studies that explicitly integrate the interactive technological affordances of AS with the contextual depth provided by SSI remain scarce, particularly in chemistry learning. This gap establishes the research gap while simultaneously opening the space for novelty, namely the development of interactive learning media that are not only visually engaging but also designed to cultivate higher-order critical thinking through the integration of socio-scientific issues. However, to date, no articulate storyline has been developed that integrates with the socio-scientific issues (SSI) approach in chemistry learning. The use of social problems in education is believed to train students' critical thinking skills (Şaşmazören et al., 2022). SSI is a pedagogical approach that combines social and scientific perspectives to address real-world problems and foster critical thinking among learners (Cebesoy & Rundgren, 2023).

Chemical bonding material is an abstract concept Rahman et al., (2024), complex and challenging to understand by students because it is not enough to rely solely on theory, but also requires learning strategies that can manage conceptual plurality, such as microscopic side visualisation to clarify understanding of atomic structure and ionic interactions (Nehring & Schanze, 2025). This difficulty increases if the material is only delivered theoretically without direct experience, which can hinder students' understanding of fundamental concepts, such as the mechanism of electron acceptance and release in ions (Sutrisno et al., 2020) To overcome these obstacles, exploratory activities are needed that encourage students in the process of investigation,

analysis, and inference, so that they can understand abstract chemical concepts more deeply and contextually (Harefa, 2020; Natasya et al., 2025).

Applying the SSI approach can be an effective strategy to help learners better understand the concept of chemical bonding while improving their critical thinking skills. A study by Gulacar et al., (2022) provides empirical evidence that discussions around socio-scientific issues (SSI) are effective in changing students' perceptions of science and their career aspirations, and recommends practical methods to encourage students to become science-literate and global citizens. In line with these findings, (2024) showed that integrating SSI into science learning significantly increased students' interest in science.

Based on previous studies, most developments of Articulate Storyline (AS)-based media in science education have focused either on enhancing visualisation and interactivity or on incorporating contextual issues through the Socio-Scientific Issues (SSI) approach. However, these two aspects are rarely combined within a single instructional design, particularly in chemistry learning. Accordingly, the identified research gap concerns the limited application of AS-based media in combination with the SSI approach within chemistry education. Addressing this gap is expected to yield theoretical contributions by advancing the development of instructional media models that unify digital interactivity and socio-scientific contexts. In addition, it offers practical contributions by providing chemistry teachers with interactive learning media that enhance contextualization, reflection, and meaningful learning experiences for secondary students.

This research aims to develop an interactive learning media in Articulate Storyline using the Socio-Scientific Issues (AS-SSI) approach to improve critical thinking skills in understanding chemical bonds. This media is designed to be interesting and easy to use by integrating text, sound, images and videos. The use of media and social issues in learning is expected to train students' critical thinking skills in solving daily life problems. The results of this study make a significant contribution to improving the quality of chemistry learning by encouraging the development of students' critical thinking skills through the application of Facione critical thinking framework-based tests. The use of articulate storyline interactive learning media designed with a socio-scientific issues approach, thus creating a more contextual, reflective, and meaningful learning experience.

Theoretically, this research contributes to the literature by offering an integrated framework of digital interactive media and SSI to enhance critical thinking. In practice, it provides teachers with an alternative instructional medium that can enrich classroom practice and motivate students to learn chemistry more meaningfully.

METHOD

This study uses a Research and Development (R&D) approach to design and develop interactive learning media on chemistry bonding materials, grounded in Socio-Scientific Issues (SSI), using the Articulate Storyline 3 application. The development model chosen is ADDIE (Analysis, Design, Development, Implementation, Evaluation). Theoretically, ADDIE was selected because it provides a systematic, iterative framework for needs analysis, learning objectives and interface design, product development, implementation in a real context, and formative and summative evaluation, allowing for repeated revisions until the product meets the expected criteria of validity, practicality, and effectiveness. ADDIE is also suitable for digital media development because each phase connects pedagogical aspects (learning objectives & indicators), content (scientific/content), and technical aspects (interaction design, multimedia, and evaluation), thereby supporting the instructional quality of the developed media (Dewi et al., 2022).

Time and Place of Research

The research was conducted at Senior High School 1 Alalak, Barito Kuala Regency, South Kalimantan Province, in the odd semester of 2024/2025 (September–October 2024).

Research Subjects and Samples (Sample Characteristics)

a. Population & Sample: The main sample consisted of two 11th-grade classes (class XI-1, n = 34; class XI-4, n = 33; total n = 67) that were selected purposively (entire courses) due to considerations of accessibility and suitability of the learning schedule.
b. Reported demographics: For each class, the following will be reported: number of participants per class, age range (15–16 years old), gender (M/F), final semester report card scores in chemistry (average and standard deviation), and basic digital literacy level (e.g., self-reported familiarity with learning platforms: high/medium/low).
c. Validators/experts: There are 4 Chemistry Education lecturers and 1 high school chemistry teacher (total = 5 experts) who act as validators of materials and media. The criteria for selecting experts are explained in the following section.

Operational Definition & Criteria for "Expert"

Operationally, an expert is defined as an individual who meets at least two of the following criteria:

a. Minimum Master's degree (M.Pd/M.Si) or Doctorate in Chemistry Education, Science Education, or Educational Technology;
b. Have ≥ 3 years of experience teaching chemistry at the upper secondary level (for teachers) or ≥ 3 years of research/publication experience related to science/educational technology learning (for lecturers);
c. Have experience or technical understanding of using Articulate Storyline or developing digital learning media;
d. Have been involved as a validator/assessor of educational instruments in previous research or development.

The selection of experts was conducted using purposive sampling, based on recommendations from the principal and the academic network of the study program. The identities of the experts were reported in summary form (qualifications, affiliations, experience) without presenting sensitive personal data.

Development Procedure (Details of Each ADDIE Phase)

The development stages used in this study are shown in Figure 1.

1. Analyse
   a. Literature study to determine competencies, learning indicators, and curriculum standards (Merdeka Curriculum).
   b. Semi-structured interviews with chemistry teachers and small group discussions with several students to identify barriers to learning chemical bonding and media needs.
   c. Results: learning objective design and media content blueprint (material, contextual SSI, and critical thinking measurement indicators).
2. Design
   a. Develop measurable learning objectives and media story maps (navigation flow, SSI scenarios, interaction types, formative evaluation).
   b. Develop a table of critical thinking test item specifications (question blueprint) based on Facione (1990) indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation.
   c. Design an essay (analytical) assessment rubric and practicality questionnaire (teacher/student), along with a learning observation sheet.
3. Development
   a. Content development (text, video, images, quizzes) and interaction coding using Articulate Storyline 3.
   b. Initial prototype creation and interface design (background created with Canva; converted into deployable files using Web2Apk Builder for mobile testing purposes if needed).
   c. Preparation of expert validation sheets (consisting of the following components: content validity, construction, language, and media/usability aspects).

4. Validation (Expert Assessment)
   a. Experts receive a validation package that includes: prototype products, validation sheets (Likert scale 1–5 for each item), assessment instructions, and open comment areas.
   b. Experts are asked to assess the following dimensions: (a) content validity (suitability of material to learning indicators), (b) scientific accuracy, (c) suitability of SSI context, (d) clarity of language, (e) interface and navigation design, (f) interactive functions (quizzes/feedback).
   c. Quantitative validity analysis was performed using Aiken's V for each item; items were considered valid if $V \geq 0.80$. In addition, qualitative comments from experts were used to revise the product. If there were items with $V < 0.80$, revisions were made and (if necessary) a second round of validation was conducted.
   d. The operationalisation of expert assessment and the Aiken formula will be explained in the instrument appendix (validation form and calculation examples).
5. Trial
   a. Individual trial: 5 students (to test readability, navigation, and technical errors). Data: completion time, navigation difficulties, open comments.
   b. Small group trial: 10 students (to observe the learning flow and initial responses to SSI-based tasks). Revisions were made after each trial phase based on feedback.
   c. Field implementation: application in two full classes (n = 67) to test practicality and effectiveness.

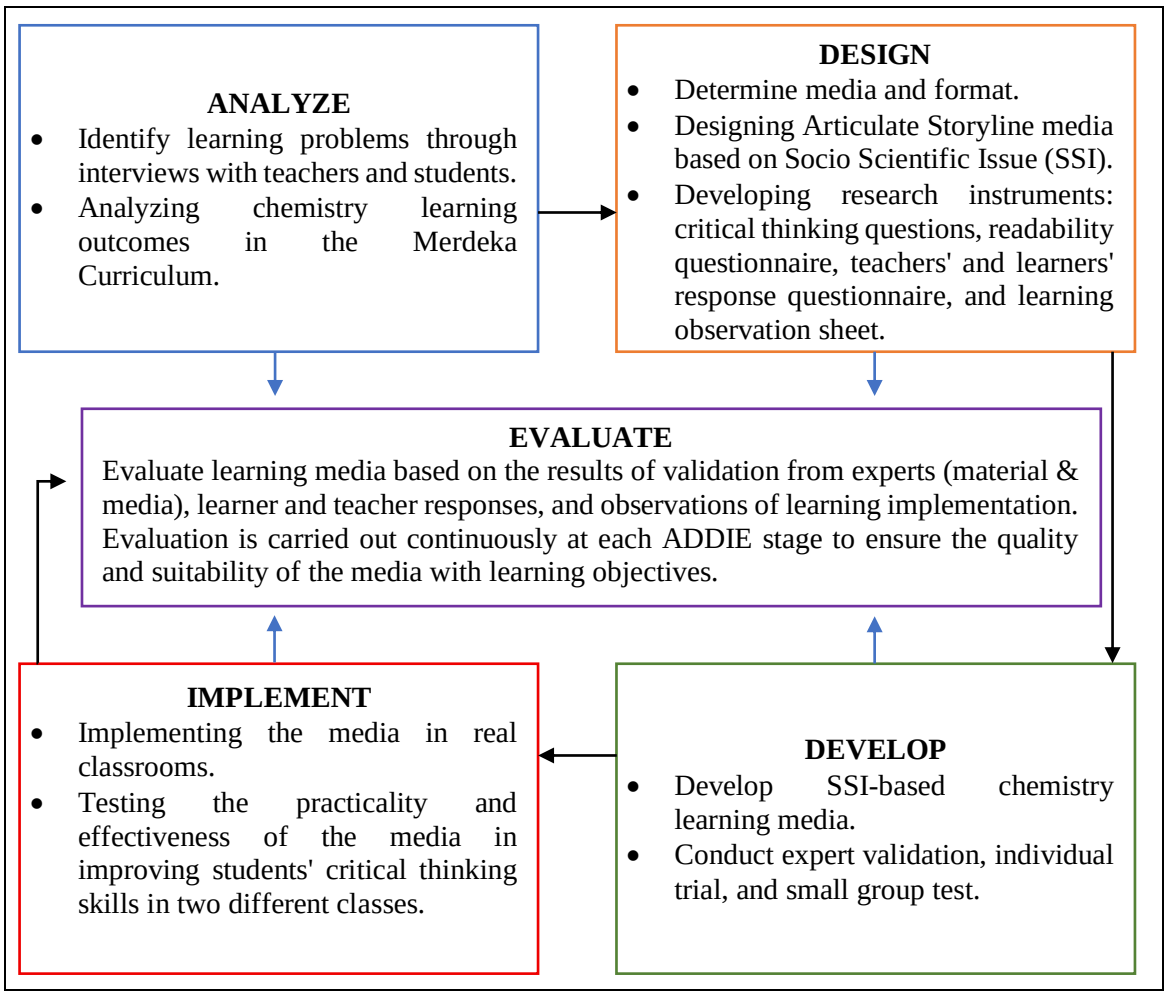

Figure 1. Steps of the ADDIE Development Model

Research Instruments

a. Expert Validation Form
   1) Likert scale 1–5 with dimensions: content relevance, conceptual completeness, scientific accuracy, language, interface & navigation, multimedia quality, and evaluation quality (quiz).
   2) Open a comment column for improvement suggestions.
   3) Analysis: Aiken's V per item & per domain; quantitative summary report plus a summary compilation of qualitative suggestions.
b. Practicality Questionnaire
   1) Administered to teachers and students after implementation; 5-point scale (1 = strongly disagree to 5 = strongly agree).
   2) Domains: ease of use, visual appeal, learning engagement, SSI relevance, and timing appropriateness.
   3) Construct validity tested through expert review; instrument reliability tested using Cronbach's alpha ($\alpha \geq 0.70$ considered acceptable).
c. Learning Observation Sheet
   1) Structured checklist to observe implementation (e.g., student engagement, use of AS features, SSI discussion activities, and time management).
   2) Two observers (researcher + trained observer) will conduct observations at several meetings; inter-observer reliability will be calculated using Cohen's kappa or percentage of agreement (threshold values will be reported).
d. Critical Thinking Test
   1) Consists of 6 items based on the blueprint (Facione, 1990); each item is designed to measure specific indicators.
   2) Analytical assessment rubric: each indicator is assessed on a scale of 0–4 (0 = no response; 4 = complete and in-depth answer). A detailed rubric is included in the appendix.
   3) reliability & Inter-rater Agreement: two independent raters will assess all responses; the Intraclass Correlation Coefficient (ICC) or Cohen's kappa will be calculated depending on the nature of the score (ICC for interval/total scores; kappa for categories). An ICC value ≥ 0.75 is considered good.

Expert Assessment and Instrument Validation Procedure (Step by Step)

1. Initial instrument development by the research team based on the curriculum blueprint and Facione (1990).
2. Submission of the validation package (media + validation sheet) to 5 experts who meet the criteria.
3. Experts fill out the validation sheet (quantitative) and write comments per item (qualitative) within 10 working days.
4. The research team calculates Aiken's V per item and domain; compiles qualitative comments.
5. Items/sections with $V < 0.80$ or receiving must-fix comments are revised. If substantial revisions are needed, a second round of validation is conducted to ensure improvements.
6. After adequate expert validation ($V \geq 0.80$ and expert agreement on key aspects), the instrument proceeds to the student trial phase.

Data Analysis Techniques: Practicality (questionnaires & observation)

1) Calculate the mean score and standard deviation for each domain/questionnaire.
2) Practicality categories use predetermined criteria (e.g., 4.20–5.00 = efficient, etc.) presented in Table 1.

Table 1. Practicality Analysis Criteria

No.	Score	Category
1	$4.20 < V \leq 5.00$	Very Practical
2	$3.40 < V \leq 4.20$	Practical
3	$2.60 < V \leq 3.40$	Practical Enough

No.	Score	Category
4	$1.80 < V \leq 2.60$	Not Practical
5	$1.00 \leq V \leq 1.80$	Not Very Practical

(Syahmani et al., 2022)

3) Questionnaire reliability test: Cronbach's alpha; report α values and item-totals if there are items with reduced reliability.
4) Observation: calculate the percentage of compliance with learning indicators; inter-observer reliability is calculated (Cohen's kappa or ICC).

a. Content Validity (Aiken's V)

1) Calculate Aiken's V for each item on the validation sheet; the formula and interpretation of the results are reported. Items with $V \geq 0.80$ are retained; V between 0.40–0.79 are revised; $V < 0.40$ are considered necessary for deletion or reconstruction. Content validity is analysed using Aiken's V formula (Azwar, 2012).

$$V = \frac{\Sigma s}{[n(c-1)]} \quad (1)$$

Description:
s = r – 1Fa
r = the number given by an assessor
1 = the lowest validity assessment number
c = the highest validity assessment number
n = number of raters

The validity assessment criteria based on Aiken's V scale are shown in Table 2.

Table 2. Validity based on Aiken's V scale

No.	Aiken's V Scale Statistics	Category
1	$V \leq 0.4$	Less
2	$0.4 < V \leq 0.8$	Moderate
3	$0.8 < V$	Valid

(Yolanda, 2020)

b. Effectiveness (Critical Thinking Test)

1) Initial step: test the normality of the pretest and posttest score distributions (e.g., Shapiro-Wilk).
2) If the data are normally distributed: perform a paired-sample t-test to test the difference between the pretest and posttest means; report the t-value, df, and p-value.
3) If not normally distributed: use the non-parametric Wilcoxon signed-rank test.
4) Calculate the N-Gain for each student and the class average N-gain; use Hake's criteria ($n > 0.7$ = high, $0.3 \leq n \leq 0.7$ = moderate, $n < 0.3$ = low). The N-Gain Score is calculated as follows:

$$\text{N-gain} = \frac{S_{post} - S_{pre}}{S_{mask} - S_{pre}} \quad (2)$$

Description:
N_{gain} = gain normality test value
S_{post} = post-test score
S_{pre} = pre-test score
S_{max} = max score

The criteria for assessing the n-gain score are shown in Table 3.

Table 3. N-Gain Criteria

No	Score N-gain	Category
1	$n > 0.7$	High
2	$0.3 \leq n \leq 0.7$	Moderate
3	$n < 0.3$	Low

(Hake, 1999)

5) Practical effect report: calculate Cohen's d (paired) to measure effect size (d = mean difference / pooled SD). Interpretation of the three categories (small/medium/large) is included.
6) If possible, additional analyses can be performed to test the influence of demographics (e.g., gender, prior ability) on critical thinking improvement using independent t-tests or ANOVA/Mann-Whitney tests as needed.

c. Reporting
1) All results are reported with descriptive values (mean ± SD), effect sizes (Cohen's d), and statistical significance (p-values). Qualitative results (expert comments and student feedback) are presented as thematic summaries to explain quantitative findings and justify product revisions.

d. Analysis Software
1) Descriptive and inferential statistical analyses were performed using statistical software (e.g., the latest version of SPSS or R). Aiken's V calculations can be performed manually or using the script/sheet described in the appendix.

RESULTS AND DISCUSSION

Results

This development produces interactive learning media for chemical bonds using AS-SSI. The following are the research results based on the stages completed.

Analysis Phase

Based on the results of the initial needs analysis, learner analysis, and material analysis, it was found that students show low interest in chemical bonding due to its abstract nature. Consequently, conventional media such as PowerPoint presentations and whiteboards are considered less effective in facilitating students' understanding of the topic (Mulyasari & Doly, 2023). Therefore, it is necessary to develop interactive learning media that integrate a social science issue-based approach, helping students better understand the material and improve their critical thinking skills.

Design Stage

This stage is a continuation of the analysis stage, where the primary focus is to design interactive learning media (Fitriyah et al., 2021), including designing media backgrounds to suit learning objectives and characteristics, then collecting videos and images supporting learning, compiling materials along with research tools and instruments to assist quantitative data collection and recapitulation during research. The results from this stage are in the form of interactive learning media using AS-SSI, ready for development, along with research tools ready for use.

Development Stage

This stage is for developing interactive learning media on chemical bonds using AS-SSI. The learning media developed is an application that can be accessed directly on a cellphone. This interactive learning media is structured with a framework that includes a login page, a user manual page, a main menu, core competencies, basic competencies, learning materials, sample questions, practice questions, and the author's bio. The parts of this interactive learning media are classified as follows:

a. Login Page
The attractive appearance of the login page aims to create a positive first impression, motivating students to be more enthusiastic about exploring the material presented. The illustration for the login page is shown in Figure 2.

Figure 2. Login Page of Interactive Learning Media

b. Instructions for Use

Instructions for use serve as an initial guide for students to understand how to interact with the media. The illustration for the instructions-for-use page is shown in Figure 3.

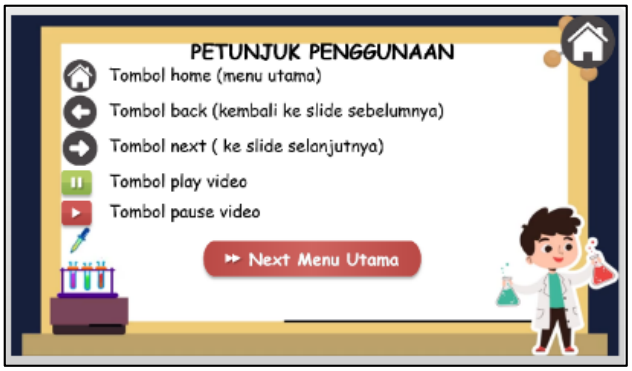

Figure 3. Instructions for Using Interactive Learning Media

The main menu page serves as a navigation hub, making it easy for learners to access media content. The illustration for the main menu page is shown in Figure 4.

Figure 4. Main Menu of Interactive Learning Media

c. Introduction Page

The introduction page features two buttons that direct users to pages containing the learning outcomes and learning objectives. An illustration of the introduction page is shown in Figure 5.

Figure 5. Interactive Learning Media Introduction Page

d. Material

This section presents learning materials and example problems using the SSI (Socio-Scientific Issues) approach. The topics covered include the duplet and octet rules, covalent bonds, ionic bonds, and metallic bonds. Students will also learn how to identify the type of covalent bond—polar or nonpolar based on the electronegativity difference between the atoms and the molecular shape. An illustration of the Materials page is shown in Figure 6.

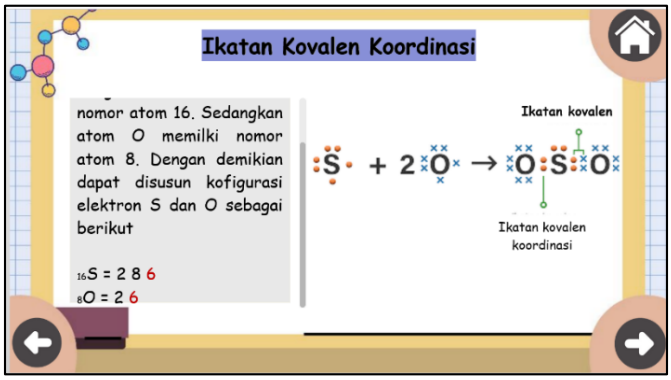

Figure 6. Interactive Learning Media Material Page

e. Evaluation

The evaluation section in this media is designed to measure students' understanding through quizzes. The illustration for the evaluation page is shown in Figure 7.

Figure 7. Interactive Learning Media Evaluation Page

A team of validators then validated the interactive learning media, testing their validity and feasibility before proceeding to the implementation stage. The validators chosen were 4 Chemistry Education lecturers and 1 chemistry teacher. This validation process involves material expert validators and media expert validators. The results of the validity test of interactive learning media using AS-SSI for material experts are presented in Table 4.

Table 4. Interactive Learning Media Validation Test Results According to Material Experts

No.	Assessment Aspects	Validator					Score Validation	Information
		I	II	III	IV	V		
1	Material Suitability	24	25	23	25	25	0.97	Valid
2	Affective Impact	10	9	10	10	10	0.98	Valid
3	Expediency	15	15	14	15	15	0.98	Valid

Table 5 presents the results of the validity assessment of the AS-SSI–based interactive learning media as evaluated by media experts.

Table 5. Results of Interactive Learning Media Validation Tests According to Media Experts

No	Assessment Aspects	Validator					Score Validation	Information
		I	II	III	IV	V		
1	Design	28	30	27	30	30	0.96	Valid
2	Language	25	24	25	25	25	0.99	Valid
3	Illustration	9	10	9	10	10	0.95	Valid
4	Typography	18	20	18	20	20	0.95	Valid

Implementation Stage

At this stage, the interactive learning media and research instruments have been improved based on feedback from experts or validators, and the results of individual and small-group readability tests were implemented in the classroom. The media, distributed in application form, are used in the chemistry learning process and can be accessed directly by both teachers and students. During this implementation phase, the practicality and effectiveness of the developed interactive learning media are evaluated. The practicality test results are based on limited-trial readability, student responses to the media, teacher responses, observations of teacher proficiency in using the media, and observations of lesson implementation. A summary of the practicality results of the interactive learning media is presented in Table 6.

Table 6. Recapitulation of Practicality Test

No.	Component	Class XI 1		Class XI 4	
		Average	Category	Average	Category
1	Legibility	4.51	Very Practical	4.40	Very Practical
2	Student Response	4.49	Very Practical	4.33	Very Practical
3	Teacher Response	4.80	Very Practical	4.80	Very Practical
4	The teacher's ability to use media	4.15	Practical	4.10	Practical
5	Learning Implementation	4.09	Practical	4.03	Practical
Score		**4.41**	**Very Practical**	**4.33**	**Very Practical**

The effectiveness of the developed interactive learning media was evaluated using students' pre-test and post-test scores. The pre-test was designed to assess students' prior knowledge and level of critical thinking skills before learning the chemical bonding material through interactive media, while the post-test aimed to measure their final understanding, specifically their critical thinking skills. The test items for both the pre-test and post-test were developed based on Facione's critical thinking skill indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation. The assessment was conducted in two classes, XI 1 and XI 4. The results of the critical thinking skills test for class XI 1 are shown in Table 7.

Table 7. Results of Critical Thinking Ability Test for Class XI 1

No.	Indicator	Pre-test	Post-test	Difference	100-Pre-test	N-gain	Category
1	Interpretation	46.32	91.17	44.85	53.67	0.83	High
2	Analysis	52.20	88.97	36.76	47.79	0.76	High
3	Evaluation	57.35	89.70	32.35	42.64	0.75	High
4	Inference	51.47	91.17	39.70	48.52	0.81	High
5	Explanation	52.94	84.55	31.61	47.05	0.67	Medium
6	Self-Regulation	47.05	91.17	44.11	52.94	0.83	High

As shown in Table 7, the indicators of interpretation, self-regulation, inference, analysis, and evaluation are in the high category, while the explanation indicator is in the medium category. The results of the critical thinking skills test for class XI 4 are presented in Table 8.

Table 8. Results of Critical Thinking Ability Test for Class XI 4

No	Indicator	Pre-test	Post-test	Difference	100-Pre-test	N-gain	Category
1	Interpretation	58.33	92.42	34.09	41.66	0.81	High
2	Analysis	45.45	85.60	40.15	54.54	0.73	High
3	Evaluation	37.87	84.09	46.21	62.12	0.74	High
4	Inference	49.24	92.42	43.18	50.75	0.85	High
5	Explanation	57.57	90.15	32.57	42.42	0.76	High
6	Self-Regulation	45.45	84.09	38.63	54.54	0.70	High

While Table 8 shows that the most significant increase is the inference indicator, followed by indicators of interpretation, explanation, evaluation, analysis, and self-regulation, all in the high category. From these two datasets, it can be concluded that the developed interactive learning media is efficacious in improving all indicators of critical thinking skills.

Evaluation Stage

Evaluation is carried out at every stage of development to ensure the quality of the outcomes. Furthermore, a comprehensive assessment is conducted at the end of the study to review all completed stages. This process aims to refine the interactive learning media tested in two classes, enabling further development and making them ready for dissemination and sustainable use in chemistry learning.

Discussion

Innovation in school learning has been proven to have a significant positive impact on the quality of the learning process. For example, a meta-analysis concluded that the use of innovative learning methods or approaches in mathematics and science can improve students' overall learning achievement (Niza & Suyanto, 2023). These findings indicate that teachers need to provide media and strategies that can stimulate student engagement, so that learning is not only informative but also transformative.

One crucial aspect that can be improved through learning innovation is critical thinking skills. These skills develop when students are exposed to media that require them to analyse, evaluate, and compare information independently. Previous studies have reported that the application of e-learning and digital media in learning has a significant impact on improving students' critical and creative thinking (Indriani et al., 2023). Thus, integrating appropriate learning media is an essential foundation for honing students' thinking skills.

Articulate Storyline is one of the interactive media that can support the development of critical thinking skills. Through interactive features, diverse media visualisations, and the ability to provide immediate feedback, this media allows students to be actively and reflectively involved in the learning process. The use of simulations, graded questions, animations, and visual icons can trigger students to ask questions, discuss, and build arguments critically. Several features, such as interactive buttons, structured quizzes, multimedia/HTML output, and branching that allows for different learning paths based on student responses, make Articulate Storyline a medium that is not only interesting but also capable of stimulating deep thinking (Miftahurrahman et al., 2024).

In this study, Articulate Storyline was further developed by integrating SSI as a learning context. This integration expands the use of Articulate Storyline from merely supporting conceptual understanding to learning that demands ethical, scientific, and social reflection in real life. This approach aligns with previous findings, which confirm that science learning using Articulate Storyline can increase student engagement and learning outcomes (Juhaeni et al., 2021). The difference is that this study emphasises that combining Articulate Storyline with SSI can lead students to engage in a more comprehensive critical thinking process, requiring them not only to understand concepts but also to consider social implications and make decisions based on scientific arguments.

The results of this study indicate that the validity of the SSI-based Articulate Storyline media developed falls within the valid category, with scores of 0.98 for material validity and 0.96 for media validity. This is in line with the research by Nuzulah et al. (2023) and Pratiwi & Alim (2022), which show that learning media developed with an Aiken's V value ≥ 0.80 falls into the highly valid category and is ready for implementation in the learning process. Meanwhile, if the validation score is ≤ 0.4, which falls in the less valid category, the interactive learning media based on an articulate storyline must be revised extensively in accordance with the suggestions and input from subject matter experts, media experts, and teachers (Adhiana et al., 2022).

The practicality of this media was also assessed based on teacher and student responses, and a practicality test score of 4.33 was obtained, indicating it is convenient. This means the media are easy to use and flexible, so they can be used anytime, anywhere, as part of the learning process about chemical bonding. This is in line with research on the practicality test results of the articulate storyline interactive learning media conducted by Ananda et al., (2024) which reported a practicality test score of 4.32 in the convenient category, indicating that the articulate storyline media is easy to use in the learning process. The practicality of this media is also reinforced by the integration of SSI, which has been proven to make students more enthusiastic about discussing and actively participating during learning.

The effectiveness of the media was also demonstrated by improvements in students' critical thinking skills after using SSI-based Articulate Storyline media. This was also confirmed by several previous findings by Rea et al., (2024); Sudiasih et al., (2022); Wijayanti et al., (2022) and Wahyuni et al., (2022), who stated that the use of Articulate Storyline can help improve students' critical thinking skills because interactive learning media are effective in arousing interest, increasing motivation, stimulating learning activities, and facilitating understanding because the material is presented interestingly. However, this study provides new evidence that effectiveness is higher when learning content is linked to socio-scientific issues relevant to everyday life, such as environmental and health issues.

Interactive learning media using AS-SSI are categorised as effective. This means that the media can improve students' critical thinking skills. This is in line with the research by Heliawati et al., (2022) which states that gamification-based multimedia articulate storyline 3 will be considered adequate if it obtains an N Gain value of ≥ 0.3, which is classified as moderate or high.

The improvement in students' critical thinking skills, as evident in the learning outcomes, is insufficient to conclude that the developed interactive learning media is effective overall. The effectiveness of the media needs to be further analysed based on each indicator of critical thinking skills, namely interpretation, analysis, evaluation, inference, explanation, and self-regulation, through questions that represent each of these competencies.

Based on the data obtained, the lowest n-gain score was observed in questions with explanation indicators in class XI-1, in the moderate category. This low score was due to the explanation indicator requirement that students provide structured, logical reasons for their answers. Difficulty in relating answers to the concepts learned was one of the contributing factors. This aligns with Laliyo et al., (2023), who stated that students often have difficulty constructing logical, structured scientific explanations, especially in chemistry. However, the moderate category is still considered adequate because it is not classified as low. In addition, in class XI-4, the n-gain score for the explanation indicator was in the high category. Thus, the six questions developed are effective in improving students' overall critical thinking skills.

This study shows that the development of SSI-based media has a strong implication for improving students' critical thinking skills. By engaging with real-world problems, students are trained to analyse data, evaluate arguments, and make evidence-based decisions. The use of Articulate Storyline makes learning more interactive, as students not only receive information but also practice identifying problems, finding solutions, and building arguments through videos and quizzes, which are then reinforced with a complex and relevant SSI approach. These findings are supported by research by Indriani et al., (2023) which shows that interactive digital media can improve students' critical thinking skills.

In addition to contributing to chemistry learning and the development of critical thinking, this study also has implications for educational management by emphasising the importance of using technology as a learning innovation. However, the media is still limited to Android devices, does not yet support iOS, and is large, requiring more storage space. These limitations form the basis for further development so that the media is more device-friendly, efficient, and can be researched in a broader context.

CONCLUSION

This study produced interactive learning media on chemical bonding using AS-SSI, which has been proven valid (0.97), practical (4.33), and effective (n-gain = 0.77), placing it in the high category. The implications of this study confirm that integrating SSI into Articulate Storyline media can enrich learning, shift the focus from mere mastery of concepts to critical thinking, help students find solutions, and increase their sensitivity to social and environmental issues.

The use of SSI-based Articulate Storyline opens up new opportunities for teachers to create more contextual, interactive, and meaningful learning experiences. Teachers are encouraged to begin integrating the SSI approach into the design of digital learning media to further hone students' critical thinking skills.

For further research, similar media can be tested with other materials or in different classes. They can also be developed with features for home and group learning to strengthen students' independence and collaborative learning. Thus, this study makes a real contribution to the development of education and opens up new opportunities for innovation in the use of SSI-based digital technology. Recommendations for further research include using the professional Articulate Storyline to support the HTML5 format so that it can be accessed on various smartphones, using premium Web 2 Apk Builder software for conversion, replacing videos with online links so that the files received by students are not too large, and involving more schools in future research.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (401-407)
Online: http://journal.uny.ac.id/index.php/jitp

Understanding educators' approaches to teaching mechanical systems and control in grade 8

Esie Zandile Msimango *, Thokozani Isaac Mtshali
Tshwane University of Technology, South Africa.
***** Corresponding Author. E-mail: esiemsimango@gmail.com

ARTICLE INFO

Article History
Received:
9 August 2025;
Revised:
19 October 2025;
Accepted:
20 October 2025;
Available online:
31 December 2025.

Keywords
Demonstration;
Mechanical systems and control;
Pedagogical strategies;
Technology education

ABSTRACT

The quality of instruction in Mechanical Systems and Control significantly impacts learners' grasp of technology concepts in Grade 8. The objectives of the research were: (1) to determine how Grade 8 educators applied pedagogical strategies to teach Mechanical Systems and Control, and (2) to assess the specific practices used in the classroom. Using a qualitative approach, data were collected through non-participant observations, semi-structured interviews and open-ended questionnaires conducted with seven (7) Technology educators across Madibeng schools. Data was transcribed and analysed using the 6 steps of thematic analysis. The findings revealed that while educators used a variety of teaching approaches such as demonstrations, practical tasks and learner-centred discussions, there was a lack of consistency between theory and practical application due to resource constraints and limited professional development. Educators expressed a preference for interactive and hands-on strategies; challenges such as large class sizes and time limitations were reported. The study recommended targeted training workshops and curriculum alignment to enhance teaching effectiveness. These findings contributed to a deeper understanding of pedagogical practices in Technology education. For further research, a mixed-method approach could provide a more comprehensive understanding by using learner performance data to evaluate the effectiveness of various teaching strategies.

How to cite:
Msimango, E.Z., & Mtshali, T.I. (2025). Understanding educators' approaches to teaching mechanical systems and control in grade 8. *Jurnal Inovasi Teknologi Pendidikan. 12*(4), 401-407. https://doi.org/10.21831/jitp.v12i4.89065

INTRODUCTION

Mechanical Systems and Control is an essential aspect of South Africa's Grade 8 Technology curriculum, as it introduces learners to fundamental engineering principles such as levers, links, pulleys, gears, and mechanical advantage. This content area not only promotes technical knowledge but also stimulates the development of problem-solving, critical thinking, and design skills, all of which are essential in STEM education (Molefe & Ramabenyane, 2019). However, the success of delivering this subject is strongly dependent on educators' pedagogical skills, confidence and classroom techniques.

Regardless of the curriculum's aims, multiple studies show that Technology educators frequently struggle to teach Mechanical Systems and Control effectively. These include a lack of material knowledge, inadequate professional development, limited access to teaching tools and

excessive class sizes (Naidoo, 2022). As a result, teaching is usually restricted to textbook-based, educator-centred instruction, limiting learner participation and engagement (Motsamai & Makgato, 2021). This approach opposes the CAPS curriculum's emphasis on hands-on, activity-based learning, in which learners are supposed to explore and generate meaning by designing, creating and assessing assignments.

Research indicates that learners fail to grasp abstract mechanical concepts without hands-on experimentation and visual aids (Maharaj & Moodley, 2023). As a result, learner-centred educational approaches such as inquiry-based learning, collaborative problem-solving and the incorporation of digital simulations have been found to improve retention and understanding in technical courses (Ngobeni & Dlamini, 2023). However, the application of these creative solutions is patchy, particularly in underserved schools.

Pedagogical decisions are likewise significantly influenced by educators' opinions (Ramaligela, 2021). Educators' decisions to embrace innovative approaches or adhere to conventional ways are frequently influenced by their opinions regarding the benefits, viability and results of various teaching methodologies (Makhetha & Wyk, 2021). Some educators recognise the advantages of practical work but are deterred from holding frequent practical sessions due to concerns about classroom management, safety, time limits and limited resources.

The novelty of this study lies in its focused exploration of how Grade 8 Technology educators teach Mechanical Systems and Control, a sub-concept often overshadowed in broader studies of technology education. While several studies explored Grade 8 Technology educators' pedagogical content knowledge generally, there is a gap in understanding how educators specifically teach Mechanical Systems and Control. Little is known about how educators reconcile pedagogical content knowledge and content knowledge during lesson enactment.

Adequate provision of teaching and learning resources, such as tools and instructional models, is essential to support meaningful learning experiences (Rahman & Lestari, 2025). Although numerous studies have explored the concept, limited empirical attention has been given to teaching methods. In the Madibeng context, these challenges are intensified by disparities in resource distribution and limited access to professional development.

METHOD

Type of Research

To understand Educators' approaches to teaching Mechanical Systems and Control in Grade 8, this study employed a qualitative research method. This approach was deemed appropriate because it allowed for an in-depth exploration of educators' pedagogical practices, perceptions and contextual challenges within real classroom settings (Lahiri, 2023).

Time and Place of Research

The study was conducted from June to July 2025. The research was conducted with a purposively sampled group of 07 educators from public schools within the Madibeng sub-district in North West province, South Africa. Purposive sampling was used to select participants who were knowledgeable and experienced in teaching Mechanical Systems and Control (Maree, 2020). Participants included Technology educators with at least 2 years' experience, ensuring insights were drawn from individuals with established classroom practices. The biographical data of the educators based on qualifications and experience can be interpreted as shown in Table 1. This biographical information is relevant because this study used expert purposive sampling. These educators are experts in Technology subjects and have 2 or more years of experience in the field.

Table 1. Biographical Data of Educators

No.	Educators	Qualifications & Experience
1	Educator A	B. Ed Technology - 3 years
2	Educator B	STD Technical - 22 years
3	Educator C	B. Ed Technical - 4 years
4	Educator D	B. Ed Natural Sciences - 6 years

No.	Educators	Qualifications & Experience
5	Educator E	ACE Technology - 4 years
6	Educator F	B. Ed Technology -13 years
7	Educator G	STD Technical - 10 years

Data Collection

Three qualitative methods were used to collect the data: non-participant observations, semi-structured interviews and open-ended questionnaires. Without interfering with the lesson's organic flow, non-participant observations provided the researcher with personal knowledge of teaching strategies, classroom dynamics, and the level of practical participation (Patton, 2022). Educators were able to describe their thinking, experiences, and difficulties through semi-structured interviews, which offered a flexible framework for discussing educational decisions (Bertram & Christiansen, 2019). Participants were allowed to write down their ideas using open-ended questionnaires, resulting in more insightful and detailed data.

Data Analysis

The six-phase model developed served as the guidance for the recording, transcription and thematic analysis of all data, as shown in Figure 1 below. Finding patterns and themes in the various data sources was made possible via thematic coding. To allow themes to arise inductively from the data rather than be imposed beforehand, a grounded theory technique was used (Charmaz, 2020). Triangulation, member checking and audit trails were among the techniques employed to guarantee the reliability of the results (Lincoln & Guba, 2018). Strict adherence to ethical protocols was maintained, including obtaining informed consent from each participant, ensuring anonymity, and obtaining ethical clearance from the appropriate educational authorities.

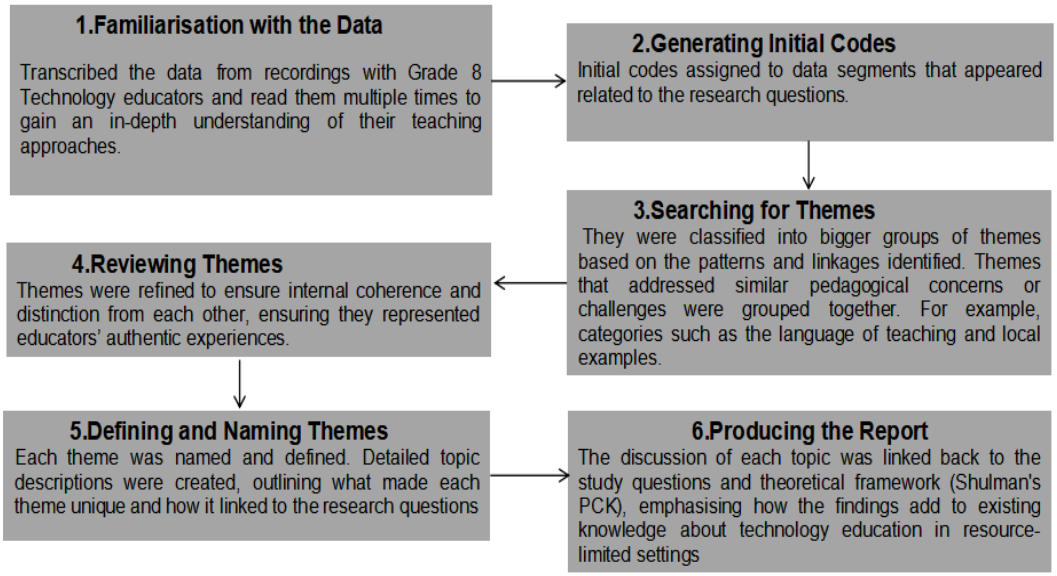

Figure 1. Braun and Clarke Model Chart based on the Research Process

Ethical Approval

Research permission was obtained from the Tshwane University of Technology Institutional Ethics Committees and from the authorities at the Department of Education and the Madibeng sub-district offices. Ethical principles were followed throughout the entire research. Participants were informed about the purpose of the research, their voluntary participation and their right to withdraw at any time without penalty. Written informed consent was obtained from all participants. The Grade 8 technology educators were notified of the study and completed the consent form indicating their voluntary participation. The participants had the right to withdraw at any time without having to specify the reasons.

RESULTS AND DISCUSSION

Results

The analysis of data collected through non-participant observation, semi-structured interviews, and open-ended questionnaires revealed several key themes regarding educators' approaches to teaching Mechanical Systems and Control in Grade 8. The results are presented under the following major themes. (1) Create scenarios for learners in order to enact prior knowledge, (2) Use various methods to prepare for lessons, and (3) Practical work enhances learner knowledge.

To add a comprehensive research instrument table that aligns with the research questions, data collection instruments, applicable frameworks and emerged themes from the study, the following Table 2 can be constructed using the detailed methodology and thematic focus described in the document:

Table 2. Research Instrument Table and Emerged Themes

No.	Research Question	Data Collection Instrument	Applicable Frameworks	Emerged Themes/Focus Areas
1	How do Grade 8 Technology educators apply pedagogical approaches to teach Mechanical Systems and Control?	Document Analysis, Non-participant Observation	Content knowledge and Pedagogical content knowledge	Create scenarios for learners in order to enact prior knowledge
2	Which pedagogical practices do Grade 8 Technology educators use to teach Mechanical Systems and Control?	Semi-structured Interviews, Open-ended Questionnaires	Content knowledge and Pedagogical content knowledge	Use various methods to prepare for lessons. Practical work enhances learner knowledge.

Create Scenarios for Learners in Order to Enact Prior Knowledge

According to the majority of educators, they start their classes by constructing realistic, real-world scenarios that draw on students' past knowledge. For instance, Educator A described how she asked learners to consider how they use equipment like wheelbarrows and bottle openers at home to teach the idea of levers. According to Educator D, learners' engagement and comprehension increase when they can relate abstract mechanical principles to familiar settings through shared experiences. This assertion was corroborated by observations that revealed classes frequently began with brief discussions or real-world problem-solving exercises. Educator G noted that some learners, particularly those with limited exposure to tools or mechanical devices outside the classroom, are unable to connect past experiences to mechanical systems.

Use Various Methods to Prepare for Lessons

Each of the seven educators reported using a variety of methods to get ready to teach mechanical systems and control. While Educator E emphasised the value of creating lesson plans and visual aids in advance, Educator B noted the importance of leveraging online resources and YouTube videos to enhance textbook content. During departmental meetings, educator C saw that working together with colleagues was very beneficial for resource sharing and lesson planning. Despite these initiatives, several educators acknowledged that a barrier to confident lesson preparation was the lack of access to training for educators in mechanical subjects. For example, Educator F mentioned that although he uses the CAPS paper as a reference, he often feels it is too general and lacks concrete examples.

Practical Work Enhances Learner Knowledge

Every participant agreed that hands-on experience is crucial to learners' comprehension of mechanical systems and control. According to observations, learners were more attentive and engaged in class during practical exercises. Using thread and plastic reels, Educator D showed

students how to construct basic pulley systems, sparking lively class debates and problem-solving. Educator A stressed that hands-on activities help students "see theory come to life," which increases their engagement and retention. Educators G and F, however, expressed concerns about inadequate supplies and equipment, which frequently limit the quantity and quality of hands-on learning. Educators reported using inexpensive or repurposed materials to adapt in schools with limited resources, but they noted that this required much more preparation time. Moreover, Educator C highlighted that there are inadequate materials for practicals, while utilising the smartboard, to provide learners with at least visual images and worksheet demonstrations. See Figure 2 below.

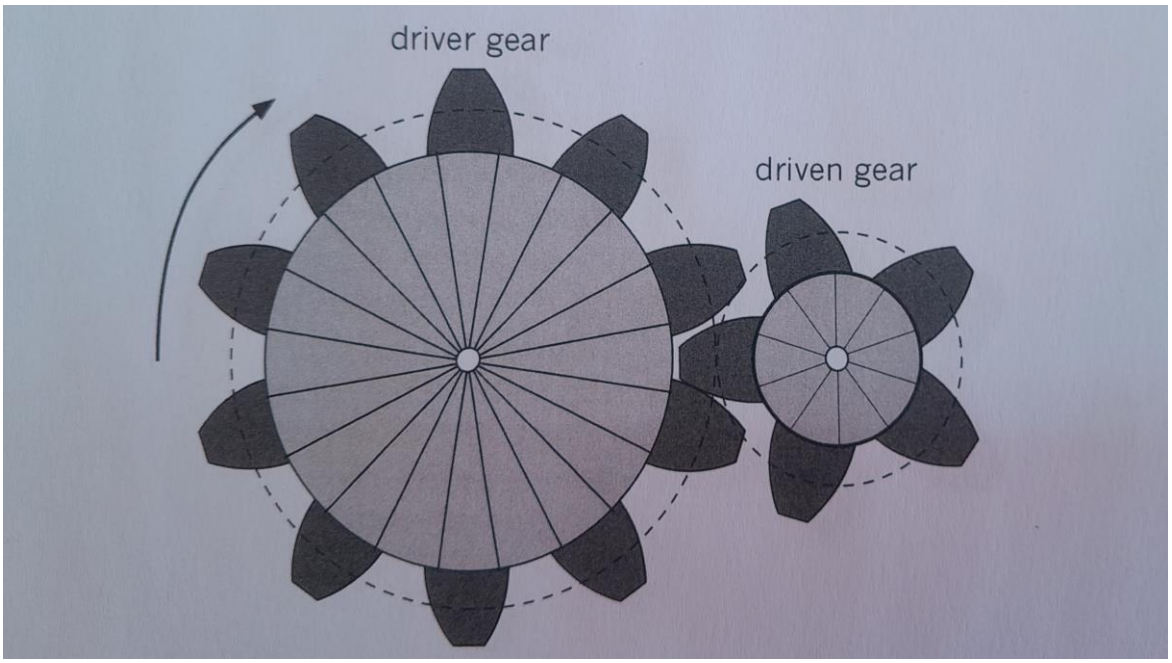

Figure 2. Educator D Worksheet Demonstration of Driver and Driven Gear

Discussion

One tactic frequently employed by participants is the use of real-life scenarios to stimulate learners' prior knowledge. Educators feel that putting lessons in context with familiar items makes it easier for learners to understand abstract mechanical ideas. Constructivist learning theory, which holds that students create new knowledge on the basis of prior experiences, is consistent with this conclusion (Maharaj & Moodley, 2023). According to studies by Motsamai & Makgato (2021), technology educators frequently rely on real-world applications to present mechanical systems and interest learners. Participants noted that not all students, particularly those with limited resources, could readily relate to mechanical instruments. This supports the findings of Letsoalo & Bhebhe (2024), who discovered that socioeconomic background can restrict students' access to mechanical devices, making it more challenging to transfer knowledge.

Lesson Preparation

According to Achmad & Mulyati (2023), educators used a range of lesson preparation techniques, including creating visual aids and diagrams, using web resources, and engaging in peer collaboration. Despite a lack of official training in mechanical systems, these initiatives demonstrate a commitment to improving instruction quality. Nonetheless, several educators acknowledged that they relied primarily on the CAPS document, which they found too general and lacking helpful advice. This aligns with Naidoo (2022) findings, which showed that educators frequently felt unprepared to teach technical material due to deficiencies in their professional development. Additionally, although peer support is seen as helpful, collaboration was often sporadic and informal due to the lack of official professional learning networks.

Practical Work

Although all educators acknowledge the value of practical work in improving learners' comprehension, resource limitations prevented some from putting it into practice. Learner engagement and conceptual knowledge clearly increase in areas where practical activities were carried out. Highlight that practical tasks promote deeper learning and retention in technology education, which validates their earlier findings. As suggested by Molefe & Ramabenyane (2019), the need for a more structured integration of practical components is highlighted by the significant learner responses observed during practical sessions. Time restrictions, packed classrooms, and restricted access to resources were mentioned as the main obstacles.

Educators have positive opinions about the subject and acknowledge its importance in providing students with life and career skills (Ndlovu & Mtshali, 2025). However, their confidence and effectiveness in instruction were weakened by the lack of focused instruction in mechanical systems. This reveals a significant discrepancy between educator readiness and curriculum expectations. The results corroborate those of Makhetha & Wyk (2021), who advocate for frequent professional development workshops explicitly focused on mechanical systems and hands-on teaching methods. These findings highlight the importance of ongoing in-service training, peer collaboration and improved resourcing to support Technology educators.

Limitations

The study is limited to the Madibeng sub-district and focused solely on Grade 8 technology educators. The sample size is limited (seven educators), and the generalizability of the results is limited. Time constraints restrict the number of classroom observations per educator. Furthermore, as a qualitative study, the findings reflect the researcher's subjective views; however, procedures such as triangulation and member verification are used to increase credibility.

CONCLUSION

This study aims to understand how Grade 8 Technology educators approach the teaching of Mechanical Systems and Control, focusing on the pedagogical methods they employ, the practices they use, and their perceptions of these approaches. The findings reveal that educators actively use real-life scenarios to activate prior knowledge, employ various strategies to prepare for lessons and value practical work as essential to learner understanding. However, despite these efforts, many face significant challenges, including limited resources, a lack of structured training, and time constraints, particularly in under-resourced schools. The conclusion drawn from these findings is that while educators demonstrate creativity and commitment, the effectiveness of their teaching is often compromised by systemic barriers. This highlights a misalignment between curriculum expectations and classroom realities. Based on these facts, it is evident that the successful teaching of Mechanical Systems and Control requires more educator effort.

Future research could expand this study by comparing the instructional practices of technology educators across different districts. A mixed-methods approach incorporating learner performance data may offer deeper insights into the effectiveness of various teaching strategies. The study has a limited number of Grade 8 Technology educators and is based around a single district. Additionally, examining how educator training programmes develop CK and PCK, along with evaluating how the CAPS document supports or limits innovative technology teaching, would provide valuable directions for improvement. Future studies should explore scalable professional learning models to strengthen practical teaching in Technology education.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (408-418)
Online: http://journal.uny.ac.id/index.php/jitp

Growth mindset and innovative ideas: The critical role of beliefs about intelligence among higher education students

Moh. Sulthon Amien[1], Achmad Hidayatullah[2] *, Rafista Deviyanti[3], Sri Lestari[4]
[1] Universitas Muhammadiyah Surabaya, Indonesia.
[2] Universitas Muhammadiyah Surabaya, Indonesia.
[3] Universtas Lampung, Indonesia.
[4] Universitas Muhammadiyah Surabaya, Indonesia
* Corresponding Author. E-mail: achmadhidayatullah@um-surabaya.ac.id

ARTICLE INFO

Article History
Received:
25 July 2025;
Revised:
22 October 2025;
Accepted:
3 November 2025;
Available online:
31 December 2025.

Keywords
Beliefs; Fixed mindset;
Growth mindset;
Innovative ideas;
Students

ABSTRACT

The purpose of this study is to explore the levels of innovative thinking, growth, and a fixed mindset among higher education students in Indonesia. This study also examined the association between mindset and innovative ideas. This cross-sectional study involved 294 students from 2 higher education institutions. Descriptive statistics, t-test, and regression analysis were employed to analyse the data. The results of this study suggest that most students tend to generate new ideas frequently. Students in the health program have lower growth beliefs, growth practices, and effort, and firmer fixed beliefs than students in another program. A growth mindset significantly predicts the generation of innovative ideas. This study contributes to the literature review and teaching practice.

How to cite:
Amien, M. S., et al., (2025). Growth mindset and innovative ideas: The critical role of beliefs about intelligence among higher education students. *Jurnal Inovasi Teknologi Pendidikan. 12*(4), 408-418. https://doi.org/10.21831/jitp.v12i4.88707

INTRODUCTION

Over the last decade, the urgency of promoting students' innovative ideas has been a central focus in higher education. The extent to which higher education should be more innovative to produce innovative ideas has been discussed in many places around the world (Jurgena & Cēdere, 2016). Innovation, as the product of an innovative idea, can be defined as a process of introducing something better or of creating a never-before-seen item of hardware (Krskova & Breyer, 2023; Tanuwijaya et al., 2024). Nowadays, innovation in digital technology, such as the revolution in algorithms for artificial intelligence, can support education on the one hand (Afriani et al., 2024) and create uncertainty about the future of professions on the other hand (Harari, 2018). Researchers argued that those who can generate new ideas, solve problems, and think outside the box would have an advantage in surviving in a dynamic world (Bedir, 2019). Accordingly, higher education should rethink how to shape students' innovative ideas.

In the higher education context, stimulating students' innovative ideas can take many forms, ranging from simple innovations, such as creating a start-up product, to creative solutions to overcome social problems. From a cognitive science perspective, Dweck (2012) stated that cognitive skills, behaviours, attitudes, and academic performance are determined by mindset. For instance, some students with high ability may perform poorly and achieve little in life. At the same time, other students with lower intelligence perform better in school and accomplish far more than one might expect (Dweck, 2002). The differences in this performance result from students' beliefs about their intelligence or mindset (Dweck, 2002). Accordingly, an innovative idea may also be associated with a mindset.

In real life, those with a growth mindset tend to overcome obstacles through innovative solutions and to be resilient when they face difficulties (Claro et al., 2016; Liu & Tong, 2022). A growth mindset is the belief that thinking ability and intelligence can be developed through specific means, such as education and experience (Barbouta & Barbouta, 2020; Limeri et al., 2020; Seo et al., 2019). In an academic context, students with a growth mindset view challenges, such as complex tasks and exams, as opportunities to learn and improve their abilities. Conversely, those with a fixed mindset tend to avoid social problems and difficulties because they think their ability cannot overcome challenging situations. A fixed mindset is the belief that intelligence and ability are fixed and unchangeable (Dweck & Leggett. Students with a fixed mindset may tend to avoid obstacles, rely on familiar strategies, and limit their effort to discover solutions that may hinder the generation of innovative ideas (Hidayatullah et al., 2026; Hidayatullah et al., 2023; Limeri et al., 2020; Peixoto et al., 2023).

From a policy perspective, the Indonesian government has been fostering students' innovative ideas through the curriculum and competitions. In line with behaviourism theory that stated academic performance and behaviour are determined by the stimuli or the pattern of students' behaviour, including skills to innovate, comes from the association between stimulus and response (Edwards et al., 2011), the Indonesian government sedimented the character of innovative idea through the curriculum Merdeka (Kurikulum Merdeka). Creative thinking to generate new ideas has been emphasised in each subject in the teachers' textbooks as one of the profiles of character Pancasila (Profil Pelajar Pancasila) at the school level (Kemdikbud, 2022). In the higher education context, students' innovative ideas have been stimulated through annual competition, namely the students' college creativity program or *program kreativitas mahasiswa* (Sukino et al., 2024). Through this program, students can propose their innovative projects to get funding. The funding state has been awarded to the innovative project that passed the assessor's evaluation. It can be said that higher education students in Indonesia are familiar with the concept of an innovation project competition.

Existing research recognises the critical role played by a growth mindset in promoting intelligence and academic performance. An empirical study by Rahardi & Dartanto (2021) pointed out that a growth mindset is associated with academic performance. Krskova & Breyer (2023) argued that a growth mindset is beneficial for students because it encourages them to adopt a performance-goal orientation in management to ensure future career success. Growth mindset is associated with students' academic performance, indicating that students across various economic statuses. Although the association between a growth mindset and academic performance has been extensively studied, little research has examined the relationship between innovative ideas and a growth mindset, especially in Indonesia. Existing research predominantly evaluates the effect of a growth mindset on academic achievement rather than on innovative behaviour. Consequently, whether a growth mindset significantly predicts innovative ideas remains underexplored.

Prior studies suggested that demographic factors, such as culture and educational background, influence students' skills and cognitive factors (Hidayatullah et al., 2023; Hidayatullah & Csíkos, 2023; Kismiantini et al., 2021; Seo et al., 2019). For instance, Hofer (2000) found that background study influences students' beliefs about abilities through field study. It can be stipulated that students' innovative ideas and mindset may be associated with their gender and field of study (Hidayatullah & Csíkos, 2023; Van der Beek et al., 2024; Vuletich et al., 2020).

As a result, the current study would describe the level of students' growth and fixed mindset and their influence on innovative ideas. Relevant factors, such as background studies, would also be

explored, particularly their influence on the level of innovative ideas, growth, and a fixed mindset. The research questions below would guide our research:

1. To what extent do higher education students in Indonesia demonstrate innovative ideas?
2. What is the level of growth and fixed mindset among higher education students in Indonesia?
3. Do students' innovative ideas and mindset (growth vs fixed) vary across different educational programs?
4. Do students' growth and fixed mindset significantly predict students' innovative ideas?

METHOD

Participants

The participants in the current study were students from two higher education institutions in Indonesia, comprising 164 students (55.8%) from one institution and 130 students (44.2%) from the other. The data were collected using snowball random sampling. 294 students participated in the current study, with backgrounds in Education (35%), Health (15%), and Economics (50%). The participants were 65 % female and 35% male. As we discussed earlier, the students are familiar with the innovation and creativity project since the program has been conducted annually.

Measurements

The instrument was divided into three parts. The first part contained the question about the demographic information: age, gender, and background. In the second part, the question focused on students' growth and fixed mindset. We adapted the Multidimensional Mindset Scale (Alvarado et al., 2024). Students' conceptions of their intelligence were evaluated for a growth mindset. The scales were translated into Bahasa Indonesia and contextualised with the Indonesian culture. This process involved bilingual scholars with expertise in educational psychology. We adapted six growth-mindset items into three factors. In the current study, two items were selected for each factor. For instance, "my level of intelligence has changed over time (growth beliefs)", "I feel attracted to challenges (growth challenges)", and "I believe in effort to become better (Growth practice and effort). Furthermore, six items were also selected to evaluate students' fixed mindset. For example, "My level of intelligence cannot be modified because it always has been the same since my first year (Growth beliefs)", "I prefer to avoid challenges", and "People do not need effort to improve their intelligence (fixed practice and effort)". The items were rated using 6-point Likert scale (1 = strongly disagree, 6 = strongly agree)

The third part of the questionnaire focuses on innovative ideas. In the current study, five items were adapted from the Innovative Work Behaviour Scale (Jong & Hartog, 2010). For instance, "how often do you put effort into the development of a new idea "and "how often do you create new ideas ". These scales were rated using a 6-point Likert scale (1 = never, 6 = always).

Procedures

Prior to commencing the study, ethical clearance was obtained from the Institute for Research and Community Service (LPPM) of Muhammadiyah University of Surabaya. We translated the instrument into Indonesian. The data collection was conducted online using the Google platform. Higher education students were invited to complete the questionnaire via WhatsApp numbers. Students were informed that the study is voluntary. Accordingly, they can decide whether to join the survey.

Data Analysis

The data were processed using Jeffreys's Amazing Statistics Program (JASP) software. Several steps in the data analysis were conducted in the current study. First, the normality of the data was evaluated using skewness and kurtosis (Blanca et al., 2013; Kim, 2013). Validity and reliability of the instruments were evaluated by performing exploratory factor analysis (CFA) and Cronbach's alpha (Gliner et al., 2017). In the CFA, maximum likelihood was used for parameter estimation, with a cutoff of 0.4 for loading factors (Ho, 2006). Second, descriptive statistics were employed to

evaluate the extent of students' growth mindset and fixed mindset. Descriptive statistics were also employed to evaluate students' innovative ideas. Third, students' innovative ideas and mindsets were compared based on their background studies using ANOVA. Fourth. The effects of growth and fixed mindsets on students' innovative ideas were evaluated using regression analysis.

RESULTS AND DISCUSSION

Results

Skewness and kurtosis analyses were conducted before EFA. Kline (2005) suggested that skewness values of +/-3 and kurtosis values of +/-7 for the data are not severe departures from normality. Table 1 presents the results of the skewness and kurtosis analyses for each construct in the current study.

Table 1. Mean and Normality Data

No.	Variables	Means (SD)	Skewness	Kurtosis
1	Innovative Ideas	3.84 (0.86)	0.20	- 0.41
2	Growth Beliefs	4.21 (0.87)	- 0.24	0.63
3	Growth Challenges	4.32 (1.00)	- 0.24	- 0.30
4	Growth, Practice, and Effort	4.62 (1.03)	- 0.71	0.29
5	Fixed Beliefs	2.64 (0.85)	0.29	- 0.58
6	Fixed Challenges	2.44 (0.55)	- 0.73	- 0.13
7	Fixed Practice and Effort	2.41 (0.56)	- 0.66	- 0.34

We conducted an exploratory factor analysis (EFA) to evaluate the instruments' validity. Using maximum-likelihood parameter estimates with eigenvalues > 1, the innovative ideas scale appears to be a single factor, accounting for 57% of the variance. The KMO value is 0.84, and Barlett's test of sphericity is 672. 56 ($p < 0.001$), indicating that the current study's sample is adequate (Lloret et al., 2017). The loading factors for the items ranged from 0.73 to 0.81. This means that each item on the scales was valid and could serve as an indicator of innovative ideas (Ho, 2006; Wong, 2013). The items also meet the requirement of internal reliability, as indicated by Cronbach's alpha of 0.87 (Gliner et al., 2017).

Furthermore, the EFA results for the growth and fixed mindsets showed that the scales met the validity requirements. By performing maximum-likelihood parameter estimation and identifying eigenvalues greater than 1, two factors have been identified, accounting for 47.2% of the variance. The sample meets the adequacy of EFA with the value of KMO 0.82 and Barlett's test of sphericity 1412.33 ($p < .001$). The loading factors for growth and fixed mindset ranged from 0.67 to 0.84 and from 0.45 to 0.90, respectively. The internal reliability of the two variables was 0.87 and 0.79, respectively.

Students' Innovative Ideas and Mindset

Table 2 presents students' innovative ideas and beliefs about intelligence. In general, higher education students in Indonesia expressed the ability to generate innovative ideas fairly frequently but not consistently, such as creating and developing new ideas, exploring new solutions, and attempting to discover new approaches to complete the task.

Table 2. Innovative Ideas, Growth, and a Fixed Mindset

No.	Items	Means	SD
1	**Innovative Ideas**		
	How often do you create new ideas?	3.83	1.07
	How often do you put effort into developing new ideas?	3.96	1.01
	How often do you explore new products or solutions?	3.86	1.04
	How often do you create original solutions for problems?	3.64	1.18
	How often do you find a new approach to execute a task?	3.92	1.01
2	**Growth Beliefs**		
	I can change my level of intelligence over time	4.21	0.99
	I can be smarter if i learn regularly	4.21	1.00

No.	Items	Means	SD
3	**Growth Challenges**		
	I feel attracted to challenges	4.38	1.07
	I can participate whenever there are challenges	4.26	1.19
4	**Growth Practices and Effort**		
	I believe i can improve my intelligence by putting in an effort	4.79	1.23
	I believe that by practising, I can improve the result	4.46	1.07
5	**Fixed Beliefs**		
	My intelligence cannot be changed	2.48	1.41
	If I am smart because I was born that way	2.81	1.01
6	**Fixed Challenges**		
	I prefer to avoid any challenges and difficulties	2.43	0.65
	I think I cannot overcome the challenges	2.44	0.66
7	**Fixed Practices and Effort**		
	I think effort will not change my intelligence	2.54	0.63
	I do not think I can be a brilliant student, even if I spend a lot of time studying.	2.28	0.75

With respect to the level of growth mindset, students in higher education in Indonesia generally agreed with statements in each growth mindset dimension, such as growth beliefs, beliefs in practices and effort, and beliefs about the ability to overcome challenges, even though the level of these beliefs does not reach the strongly agree category. We compare this result with other surveys in Greece (Barbouta & Barbouta, 2020), the United States (US), and China (Sun et al., 2021). Surprisingly, higher education students in Indonesia have a higher level of growth beliefs compared to Greek and Chinese students, and quite similar to US students, especially for beliefs about intelligence (M = 4.21, SD = 0.99; M = 2.7, SD =1.00; M = 3.08, SD = 0.83; and M = 4.12, SD = 1.09, respectively). Furthermore, students in Indonesia generally expressed disagreement with the fixed-mindset statements. In comparison, students in Greece tend to hold stronger fixed beliefs, such as the belief that intelligence cannot change over time (M = 3.6, SD = 0.40).

Innovative Ideas, Growth, and a Fixed Mindset from Background Study

ANOVA was employed to determine whether innovative ideas, growth, and a fixed mindset differ across students' educational backgrounds. Students' creative ideas and their growth and fixed mindsets are almost equal across different field studies. However, students' growth beliefs differ by educational background (F (2) = 3.85, $p < 0.05$). Figure 1 shows that students in the health program had the lowest level of growth beliefs compared to students in another program.

Table 3. Innovative Ideas, Growth, and a Fixed Mindset based on Educational Background

No.	Variables	Educational Background	Mean (SD)	F	*p*
1	Innovative Ideas	Economic Program	3.93 (0.76)	2.73	0.06
		Health Program	3.91 (0.99)		
		Education Program	3.68 (0.91)		
2	Growth Beliefs	Economic Program	4.32 (0.75)	3.85	0.02*
		Health Program	3.91 (1.01)		
		Education Program	4.19 (0.94)		
3	Growth Challenges	Economic Program	4.35 (0.92)	1.27	0.28
		Health Program	4.11(1.18)		
		Education Program	4.38 (1.03)		
4	Growth, Practice, and Effort	Economic Program	4.77 (0.89)	3.74	0.02*
		Health Program	4.34 (1.25)		
		Education Program	4.53 (1.08)		
5	Fixed Beliefs	Economic Program	2.82 (0.91)	8.45	< .001
		Health Program	2.27 (0.63)		
		Education Program	2.56 (0.78)		
6	Fixed Challenges	Economic Program	2.45 (0.52)	2.15	0.12
		Health Program	2.30 (0.65)		
		Education Program	2.51 (0.53)		
7	Fixed Practice and Effort	Economic Program	2.41 (0.58)	0.11	0.89

No.	Variables	Educational Background	Mean (SD)	F	*p*
		Health Program	2.38 (0.64)		
		Education Program	2.43 (0.49)		

Furthermore, significant differences have been found between growth practice and effort (F (2) = 3.74, $p < 0.05$; Fig. 2) and fixed beliefs by educational background (F (2) = 8.45, $p < 0.001$; Fig.3). Students from health program seem to have the lowest level of those beliefs consistently compare to students from economic and education program.

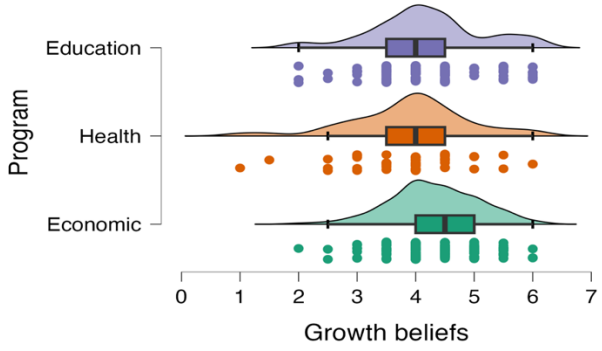

Figure 1. Result of ANOVA on the Growth Beliefs by Educational Background

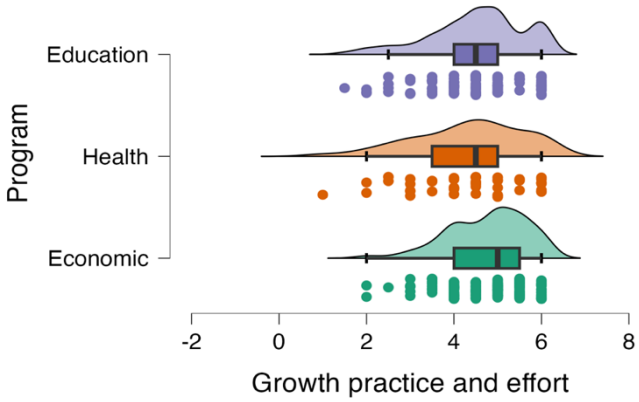

Figure 2. Result of ANOVA on the Growth, Practice and Effort by Educational Background

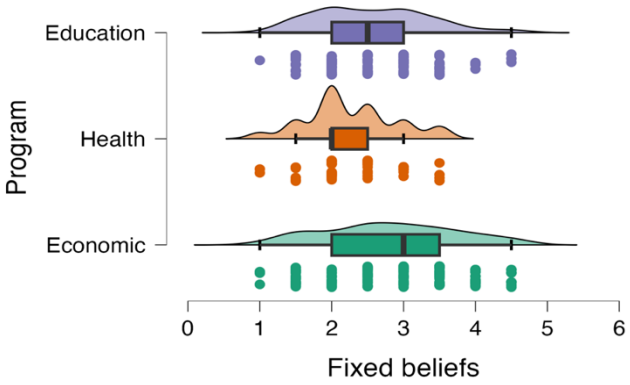

Figure 3. Result of ANOVA on the Fixed Beliefs by Educational Background

The Significant Effect of Growth and Fixed Mindset on Innovative Ideas

To evaluate the effect of growth and fixed mindset on students' innovative ideas, the current study employed multiple regression analysis (See Table 4). Growth mindset significantly predicts innovative ideas, with R2 = 33.45% ($p < .001$). In particular, growth beliefs ($\beta = 0.22$, $p < 0.05$) and

growth practice and effort (β = 0.33, p < 0.001) significantly influence innovative ideas but not growth challenges (β = 0.09, p = 0.21).

Table 4. The Effect of Growth and the Fixed Mindset on Innovative Ideas

No	Variables	r	β	r.β.100	t	*p*
1	**Growth Mindset**					
	Growth Beliefs	0.51	0.22	11.22	3.04	0.003
	Growth Challenges	0.49	0.09	4.41	1.25	0.21
	Growth Practices and Effort	0.54	0.33	17.82	4.78	< 0.001
	Total Variance Explained (R^2)			33.45%		
2	**Fixed mindset**					
	Fixed Beliefs	-0.17	-0.08	1.36	-1.34	0.18
	Fixed Challenges	-0.33	-0.19	6.27	-2.84	0.005
	Fixed Practices and Effort	-0.34	-0.21	7.14	-3.28	0.001
	Total Variance Explained (R^2)			14.77%		

Furthermore, a fixed mindset accounts for 14.77% of innovative ideas. The stronger the students' fixed mindset, the less likely they are to generate new ideas. Partially, both fixed challenges (β = -0.19, p < 0.05) and fixed practice and effort (β = -0.21, p < 0.001) negatively predict innovative ideas but not fixed beliefs (β = -0.08, p = 0.18).

Discussion

The first question in this study sought to investigate the level of innovative ideas of higher education students in Indonesia. The findings of this study revealed that students expressed their ideas fairly frequently but not consistently during the activity of generating innovative ideas. For instance, students frequently generated new ideas, explored new solutions, and attempted to discover new approaches to complete the task, though this behaviour was not consistent. This finding suggests that higher education students in Indonesia tend to generate innovative ideas, although not to a substantial extent. Accordingly, intervention and support from external sources are still necessary.

The second question in this research was the level of students' growth and fixed mindset in higher education in Indonesia. The findings of this study suggest that students agreed with statements related to growth beliefs, beliefs in practices and effort, and beliefs about the ability to overcome challenges, even though the levels of these beliefs did not reach the strongly agree category. In other words, Indonesian students agree with the notions that intelligence can be developed through intervention (Barbouta & Barbouta, 2020; Limeri et al., 2020; Seo et al., 2019). Compared with students in Greece (Barbouta & Barbouta, 2020) and China (Sun et al., 2021), Indonesian students have stronger growth beliefs. Surprisingly, the level of these beliefs about intelligence appears to be similar to that of students in the US (Sun et al., 2021). A possible explanation for this result may be Indonesian culture, which emphasises effort and self-control to achieve goals. This level is likely comparable to that of US students educated with a more psychologically positive approach. Indonesian students expressed disagreement with the fixed mindset statements, indicating that they are more open to the idea that intelligence and abilities can grow over time. This tendency indicates that Indonesian students have been more open to knowledge than students in Greece. In the US, students expressed disagreement with the fixed beliefs. Accordingly, higher education students in Indonesia are considered more open than perceived as having fixed intelligence.

The third question identified the level of students' innovative ideas, growth, and fixed mindset based on the program study background. Surprisingly, growth beliefs, growth effort, and practice have been found to differ among students across different programs. Although students from the three programs agreed with the indicators of growth beliefs, growth effort, and growth practice, students from the Economic and Education program showed a higher level of agreement with these mindsets. Furthermore, students expressed disagreement with a fixed mindset. Surprisingly, the ambiguity was identified when students in the Health program expressed the most vigorous disagreement about fixed beliefs. Although the level of agreement about students' growth beliefs in the Health program was not particularly strong, the level of disagreement with their fixed beliefs was

the strongest across programs. It could be that students from this program were not really optimistic about their intelligence. At the same time, these students also oppose the idea of fixed beliefs.

The fourth question in the current study examines the significant effects of growth and fixed mindsets on students' innovative ideas. This study found that a growth mindset significantly predicts innovative ideas. This finding aligns with existing research that has found significant effects of beliefs about intelligence on students' academic performance (Hidayatullah et al., 2024; Kismiantini et al., 2021; Rahardi & Dartanto, 2021) and on innovative thinking (Krskova & Breyer, 2023). It can be stated that when students believe their intelligence can be changed and that effort affects their achievement, it enhances their motivation to develop and create new ideas. Interestingly, a fixed mindset has been found to influence the generation of innovative ideas negatively. The stronger the students' fixed mindset, the less likely they are to generate new ideas. This finding aligns with previous studies that suggest individuals who hold beliefs about the certainty of their abilities tend to fail in academic contexts (Bai & Wang, 2020; Claro et al., 2016; Hofer, 2000). Accordingly, when students believe that intelligence is unchanging and effort is not useful, they are less likely to generate new ideas.

The findings of this study enrich the literature on the levels of innovative ideas, growth, and fixed among higher education students, as well as the relationships among those variables. In the teaching practice, changing students' fixed mindset to a growth mindset promotes innovative ideas. Emphasising students' effort or the process rather than their score in the classroom would be more beneficial for promoting a growth mindset. If students fail to generate innovative ideas even after hard work, the teacher can help them understand why their strategy is not effective and guide them with other strategies and sources to generate innovative ideas (Dweck, 2016). Teachers in higher education can also help students shape their innovative ideas by demonstrating examples of innovators and showing how far they have advanced new ideas.

CONCLUSION

This study set out to explore the extent of students' growth and the prevalence of a fixed mindset regarding their innovative ideas. Differences have been found in growth beliefs, growth practices, effort, and fixed beliefs by educational background. Moreover, both growth and fixed mindsets significantly influenced the generation of innovative ideas. Although the current study provides important insights into promoting innovative ideas in higher education, several limitations should be noted. The current study employs a cross-sectional design, where the prediction of the variables requires clarification. As we employed the snowball random sampling method, the sample in the current study may be somewhat homogenous. Accordingly, it affects the finding that it may not fully represent the broader target population. The combination of qualitative and quantitative approaches in the future would deepen the information and understanding of the relationship among these variables. Since the sample in the current study is small, future research should increase the sample size to include individuals from diverse backgrounds.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (419-432)
Online: http://journal.uny.ac.id/index.php/jitp

The role of STEM-based learning media in improving students' science literacy: A systematic review

Tina Oktasari, Sardianto Markos Siahaan *, **Leni Marlina**
Universitas Sriwijaya, Indonesia.
* Corresponding Author. E-mail: mr.sardi@unsri.ac.id

ARTICLE INFO

Article History
Received:
15 May 2025;
Revised:
18 July 2025;
Accepted:
27 December 2025;
Available online:
31 December 2025.

Keywords

ABSTRACT

In the 21st century, scientific literacy is an essential skill for students, but many challenges remain in learning it. To address these challenges, integrating STEM-based learning media offers an innovative solution by promoting contextual, interactive, and project-based learning that enhances students' engagement, critical thinking, and understanding of scientific concepts. This study aims to systematically review the role of STEM-based learning media in improving students' science literacy, identify the characteristics of effective media, and the factors that influence their successful implementation. This study used a systematic review method following PRISMA guidelines, analysing 21 selected articles from Google Scholar, Web of Science, DOAJ, and ERIC databases, with a publication range of 2019-2025. The analysis shows that STEM-based media effectively improve students' understanding of science concepts, critical thinking skills, and digital literacy. Interactive, project-based and contextualised media proved most effective. The main supporting factors for successful implementation include teacher competence, valid and practical media design, and support for the learning environment. This study emphasises the importance of integrating STEM-based learning media to improve overall science literacy. Future research is recommended to explore the long-term impact of STEM-based learning media on students' science literacy across diverse educational levels and cultural contexts, and to develop adaptive digital tools that support personalised learning and teacher facilitation.

How to cite:
Oktasari et al., (2025). The role of STEM-based learning media in improving students' science literacy: A systematic review. *Jurnal Inovasi Teknologi Pendidikan. 12*(4), 419-432.
https://doi.org/10.21831/jitp.v12i4.85336

INTRODUCTION

In the face of the dynamics of the 21st century, science literacy is a fundamental need for every individual to participate in a knowledge- and technology-based society actively. Science literacy is not only the ability to understand scientific concepts, but also encompasses critical thinking, problem-solving, and evidence-informed decision-making in daily life (Falloon et al., 2020). The results of national and international studies show that students often have difficulty in understanding scientific concepts as a whole and linking them to real-world contexts. This is inseparable from the various challenges in the science learning process in schools, such as low student interest in science, abstract and theoretical learning content, and less innovative, teacher-centred learning approaches (Santos et al., 2023). The lack of meaningful, applicable learning experiences prevents students from developing scientific thinking skills effectively (Aini et al., 2020).

STEM education is a learning innovation that equips students with the skills needed in the 21st century. The STEM-based learning approach (Science, Technology, Engineering, and Mathematics) emerged as an innovative alternative to address the challenges of current science education (Karimah & Wulandari, 2023). Implementing STEM education in learning activities can encourage students to use technology to design, develop, and improve cognitive processes and to apply knowledge (Wahono et al., 2023). The STEM approach integrates the four main disciplines harmoniously, emphasising the solution of real problems through project-based activities and exploration (Sole, 2021). STEM learning emphasises collaboration, creativity, and critical and reflective thinking, all of which support the holistic development of students' science literacy (Harpian et al., 2023). With this approach, learners not only learn science conceptually, but also apply it practically in real-life situations (Setiawan, 2019).

Numerous studies indicate that using STEM-focused learning resources can significantly enhance students' science literacy across different educational levels. For example, the use of e-modules integrating Sustainable Development Goals (SDGs) principles has been shown not only to improve understanding of science concepts but also to foster students' environmentally friendly attitudes and social care (Aswirna et al., 2022). Meanwhile, the development of worksheets based on STEM and local wisdom has also been shown to be content valid and effective in improving students' scientific literacy skills in specific topics, such as thermal energy (Ariefianti et al., 2023). The STEM approach has proven relevant to apply from the primary education level and even pre-school. Research shows that children exposed to early STEM learning show significant improvements in science and visual literacy, and have better scientific communication skills (Ramulumo, 2024). This aligns with findings that STEM learning, when delivered through integrated projects or modules, can be an effective means of developing students' scientific literacy and critical thinking skills from an early age (Aguilera & Ortiz-Revilla, 2021).

Numerous research efforts have demonstrated the benefits of STEM-based learning media in improving science literacy. However, there is no systematic study that comprehensively reviews the various forms of such media, their characteristics, and the effectiveness of their implementation in various educational contexts. Consequently, this research intends to conduct a systematic review of the existing literature on the functions of STEM-oriented learning resources and their impact on enhancing students' scientific literacy across different educational levels. Specifically, this review seeks to examine how STEM-based learning media improve students’ science literacy, identify the characteristics of effective STEM-based learning media in science education, and analyse the key factors that influence the successful implementation of these learning resources in educational institutions. The findings of this study are expected to provide educators, curriculum developers, and policymakers with valuable insights for designing and implementing more effective, engaging, and contextually relevant STEM-based learning strategies to improve science literacy outcomes.

METHOD

This study applied the systematic literature review approach as done by (Ashiq et al., 2022) to critically appraise the published literature on STEM, implementation models, benefits, challenges, impacts, and practical recommendations that can be applied by educators who want to integrate STEM in teaching practices, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. The PRISMA guidelines allow researchers to methodically document evidence-based elements that are useful for thoroughly assessing published literature, as highlighted (Moher et al., 2009; Ashiq et al., 2022). PRISMA considers four elements of a study, namely identification, screening, eligibility, and included studies. PRISMA was initially created for the healthcare sector but has proven relevant across numerous other domains. Furthermore, we utilised the PRISMA 2020 Checklist to structure the study title, objectives, methods, results, discussion, and other specifics (primarily concentrating on search details, inclusion and exclusion criteria, synthesis of results, risk of bias, etc.) (Yepes-Nuñez et al., 2021).

Search Strategy

Data for this study were collected through keyword searches across four major online academic search engines: Google Scholar, Web of Science (WOS), Directory of Open Access Journals (DOAJ), and Education Resources Information Centre (ERIC). Keywords were selected based on their relevance to STEM, learning media and science literacy. To progress to the next stage, each article had to include "STEM" or information about learning media platforms and at least one other keyword in the title or abstract. The author ran the following search on April 29, 2025. The keywords and search operators used were ("STEM-based learning media") AND ("Science literacy" OR "Scientific literacy") AND ("Students" OR "Learners") AND ("STEM education" OR "Integrated learning approach").

Inclusion and Exclusion Criteria

We incorporated all pertinent studies released from 2019 to 2025 regarding STEM-oriented learning resources. Only original peer-reviewed research articles were considered, along with studies that focused on multiple aspects of the study or accomplished at least two research goals. Included research studies include STEM implementation models, benefits, challenges and impacts encountered in the application of STEM-oriented educational resources. In addition, only English and Indonesian research articles were included. As shown in Table 1. Inclusion and exclusion criteria.

Table 1. Inclusion and Exclusion Criteria

No.	Inclusion Criteria	Exclusion Criteria
1	Articles with publication year range: 2019-2025	Published before 2019
2	Original research or systematic reviews that examine STEM-focused educational media in elementary, middle, high school, or university education settings	Studies that are unrelated to the topic of utilising STEM-focused learning resources in elementary, middle, high school, or university education
3	Article in English or Indonesian and available in full text	Written in languages other than Indonesian and English, and not available in full text
4	Articles that include the official DOI	Unreliable sources, such as personal blogs or social media, without scientific references

The identification stage involved collecting scientific articles from four central databases: Google Scholar, Web of Science (WOS), Directory of Open Access Journals (DOAJ), and Educational Resources Information Centre (ERIC). From this process, we collected 245 articles that used the keywords "STEM-based learning media" and "Science literacy" or "Scientific literacy" in their titles or abstracts. Next, we proceeded to the screening stage by removing duplicate articles, leaving 190. Then, an initial selection was made by removing articles that did not meet the criteria, such as those with inappropriate language (not in Indonesian or English) and those not at the primary, middle school, secondary school, or college levels. A total of 97 articles were eliminated at this stage, leaving 93 articles for further analysis.

Then, the eligibility stage was conducted by assessing the availability of the full texts of the articles. Twenty-five articles were removed since they were not accessible in their complete form. Out of the 68 articles left, a comprehensive examination of the material was performed. At this stage, 47 articles were excluded because they only discussed one narrow aspect, such as STEM implementation models, benefits or challenges without empirical data, and did not directly assess the influence of STEM-focused educational materials on students' scientific understanding. Finally, the inclusion phase yielded 21 articles that satisfied all the inclusion criteria and served as the primary data source for this study. The articles were then analysed to answer three research questions: the effects of STEM-based learning media, their characteristics, and the factors that affect the effective implementation of STEM-oriented educational resources. As shown in Figure 1, SLR was conducted by following the PRISMA flow.

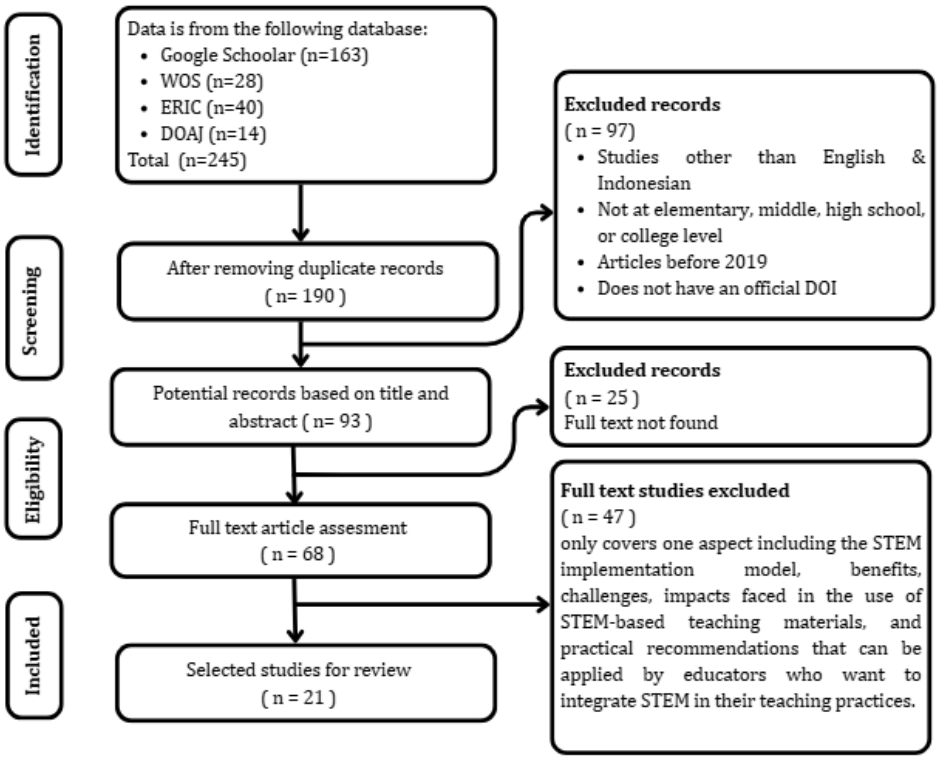

Figure 1. Four-phase Flowchart of PRISMA Guidelines

Synthesize Results

After 21 articles were collected, the next step was to analyze them systematically, starting with reading all the articles thoroughly to understand the content and essence of each article once found, then concisely recording the key points of each journal once found, then concisely recording the key points of each journal such as the purpose of the research, the methods used, the main results, and the benefits and drawbacks of utilizing STEM-focused educational tools in enhancing students' scientific literacy. The articles were also grouped by theme or research focus, such as improving science literacy, STEM-based learning effectiveness, or learning media. From these groupings, comparisons were made between journals to find patterns of similarities and differences in research results. Findings from various journals are then synthesised to develop a comprehensive understanding of the topic under study, enabling conclusions and strategic recommendations on the role of STEM-based learning media in improving students' science literacy. These articles were used as citation sources in writing scientific articles to provide a strong basis and to ensure they can be academically accounted for. Table 2 presents the findings from the examination of the 34 gathered articles.

RESULTS AND DISCUSSION

Results

Table 2. Study Analysis Results

No.	Author, Year of Publication	Title	Main Findings
1	Hamdu et al., (2021)	Learning device in the "STEMpedia" mobile learning application	The researcher created an Android mobile learning app named "STEMPedia" to serve as a resource for educators to explore STEM-based

No.	Author, Year of Publication	Title	Main Findings
			learning frameworks and obtain teaching resources. The STEMPedia app provides comprehensive teaching resources, including lesson plans, student worksheets, and STEM-based learning modules. This app has some limitations: it can only run on Android devices with version 7.0 or higher, and it may crash or close unexpectedly on older Android versions.
2	Khairani et al., (2023)	Interactive Multimedia Development Based on STEM in Improving Science Learning Outcomes	The use of STEM-based interactive multimedia improves academic outcomes in science for 5th-grade pupils at SD Negeri 104197 Klambir Village. The efficacy of engaging multimedia focused on STEM is categorised as "medium" with a gain score of 0.54. The use of STEM-based interactive multimedia increases the percentage of students who meet the minimum completeness criteria from 63.33% to 93.33%.
3	Sulistyawati et al., (2021)	Manipulative learning media based on STEM (science, technology, engineering, and mathematics) to improve student learning outcomes	Magic Hours is a hands-on learning tool developed to make learning more engaging. The results of this study proved to be valid and feasible based on the experts' evaluation. The "Magic Hours" learning media also proved practical for classroom use, as evaluated by the teachers. The "Magic Hours" educational media is successful in enhancing students' performance in mathematics, as their average score is well above the minimum passing score.
4	Hazima et al., (2024)	Implementation of STEAM and Thematic Learning Models Assisted by STEMATIK Learning Media in Elementary School	The use of STEMATIK learning media that combines STEAM and thematic learning models can significantly improve student learning outcomes. The use of STEMATIK learning media can increase students' independence and motivation to learn. STEMATIK learning media integrates various learning content, including civic education, cultural arts, and the Indonesian language, alongside mathematics.
5	Lafifa & Rosana (2023)	Development and Validation of Animation-Based Science Learning Media in the STEM-PBL Model to Improve Students' Critical Thinking and Digital Literacy	The STEM-PBL model's animation-based learning media are highly valid and suitable for use in science education. It received a 92% score from the media expert and an even higher 94% from the material expert. The assessments of the media's readability and practicality also fell into the excellent range, achieving scores of 85% and 99% respectively. The media can enhance students'

No.	Author, Year of Publication	Title	Main Findings
			abilities in critical thinking and digital literacy.
6	Artobatama et al., (2023)	STEM Learning Design with Literacy-Based Pop-Up Book Media in Elementary Schools	STEM education utilising literacy-focused Pop-Up Book resources has been developed and applied in elementary schools, and students show great enthusiasm for this learning method. Utilising literacy-centred Pop-Up Book media in STEM education can enhance students' analytical thinking, troubleshooting, decision-making, and investigative abilities. Implementing STEM education through literacy-focused Pop-Up Books encounters various obstacles, such as teachers' lack of understanding of STEM pedagogy and the need for training to address it.
7	Azizahwati et al., (2023)	Meta-analysis of the effect of STEM application on higher-order thinking skills in science learning	STEM learning is more effective at the junior high school level compared to the high school level. The PjBL (Project-Based Learning) model is the most effective STEM learning model. STEM learning using LKPD (Learner Worksheet) and modules as learning media has the highest effect size, indicating a very high impact.
8	Sakdiah et al., (2023)	Development of Augmented Reality (AR) Learning Media Integrated with STEM Learning	The created STEM-integrated AR media is regarded as highly feasible by material experts and seen as practical by media experts. The limited trial showed that the media was in the outstanding category for student practicality and the convenient category for teacher practicality. Further large-scale implementation is needed to determine the effectiveness of STEM-integrated AR media, which requires a stable internet connection.
9	Nurfadilla et al., (2022)	Science Teachers' Attitudes, Knowledge, and Practices in Applying a Gender-based STEM Approach	Both male and female science teachers had high levels of attitudes, knowledge and practices related to STEM approaches, with only slight differences between the two genders. There were no significant differences in male and female science teachers' attitudes, knowledge and practices towards STEM approaches. Male and female science teachers share similar perceptions and abilities regarding STEM approaches.
10	Agustin et al., (2022)	Meta-Analysis of the Influence of the STEM-Based Project-Based Learning (PBL)	The PjBL model, centred around STEM, showed the most significant positive effect on student learning outcomes in junior high schools, followed by high schools and

No.	Author, Year of Publication	Title	Main Findings
		Model on Science Learning	elementary schools, while demonstrating the least impact in higher education. The STEM-based PjBL model had the highest positive impact on student learning outcomes in mathematics, followed by other science subjects such as physics and biology. In contrast, the impact was moderate for chemistry. Overall, the STEM-based PjBL model has a high positive effect on student learning outcomes across different education levels and subject areas.
11	Widya et al., (2024)	Needs analysis of interactive STEM-based multimedia to enhance literacy and 21st-century skills	Students need learning media that are engaging, relevant to their daily lives, and able to foster 21st-century literacy and skills. Teachers highlight the need for practical, easily accessible educational tools that enhance student involvement in the learning experience. The development of interactive multimedia based on STEM education is needed to build students' 21st-century literacy and skills.
12	Yusuf et al., (2021)	Implementation of Online STEM-PjBL through Various Learning Platforms in Vocational High Schools during the Covid-19 Pandemic	During the COVID-19 pandemic, some teachers adopted STEM project-based learning (STEM-PjBL) in their online classrooms. Teachers utilise various online platforms, such as WhatsApp, Moodle, and Edmodo, to facilitate STEM-PJBL online learning, including for discussions and the delivery of materials. The main obstacle teachers face in implementing STEM-PjBL online learning is limited and difficult internet access.
13	Wijayanti et al., (2023)	Pengembangan Penggunaan Aplikasi Geomath Room berbasis Cience, Technology, Engineering, and Mathematic (STEM) pada Siswa	The Geomath Room app was created as a STEM-oriented digital learning resource for eighth-graders on spatial construction materials. The Geomath Room app was found to be valid, practical, and effective through expert evaluation and student testing. Learning outcomes and student satisfaction with the Geomath Room app improved after several rounds of field testing.
14	Duo & Asniza (2024)	The Effectiveness of STEM Project-based Learning on Scientific Identity: Quasi-Experimental Evidence from Chinese College Students	STEM project-based learning notably enhanced students' science identity in comparison to traditional teaching approaches. The experimental group showed higher scores across all four dimensions of science identity (interest, performance, competence, and recognition) than the control group. STEM project-based learning can be a practical approach to strengthening students' science identity,

No.	Author, Year of Publication	Title	Main Findings
			an important factor in their STEM learning and career choices.
15	Lestari & Muhajir (2024)	The Development of Hydraulic Robotic Arm as a STEM-Based Physics Learning Media	The hydraulic robot arm demonstrated its effectiveness as a STEM-oriented physics learning tool, as evaluated by specialists in materials and learning media. The incorporation of hydraulic robotic arms into STEM education helps students grasp the practical application of pressure principles, particularly those related to Pascal's Law. Utilising STEM-oriented hydraulic robotic arms can enhance students' critical and creative thinking, boost self-confidence, and develop problem-solving abilities.
16	Kurniawan et al., (2023)	Effectiveness of STEM-Based Lectora Inspire Media to Improve Students' HOTS in Physics Learning	The STEM-focused Lectora Inspire media is an efficient learning resource for students, as evidenced by high scores from subject-matter and media experts. Both science teachers and students rated STEM-based Lectora Inspire media as very practical and efficient for learning. The use of STEM-based Lectora Inspire media significantly improved students' higher-order thinking skills (HOTS).
17	Melita et al., (2023)	Development of STEM-Based Physics Learning Media Materials on Temperature and Heat to Improve Students' Mastery of Concepts	STEM-oriented physics education resources, represented by a digital calorimeter, are deemed highly valid, achieving an average Aiken-V score of 0.94 and a reliability rate of 93% across all associated tools. STEM-based physics learning media is considered practical, with an implementation score of 70% in each learning phase, and received positive responses from students and teachers. STEM-based physics learning media is considered effective in improving students' concept mastery, with a mean N-gain score of 0.61, placing it in the medium range.
18	Zulirfan & Yennita (2022)	Feasibility test of STEM at Home Prototype Kit as Science Project-Based Learning Media for Junior High School students	The STEM Project Kit for Home and Worksheets, developed for the topic of Simple Machines, has been validated by experts and found suitable for use as learning media. One-on-one and small-group evaluations with students indicated that the Home STEM Project Kits and Worksheets are easy to use, flexible, and effective at enhancing students' critical and creative thinking skills. The Home STEM Project Kits and Worksheets were found to be flexible in terms of location and timing,

No.	Author, Year of Publication	Title	Main Findings
			with most students able to work on the projects independently at home.
19	Irfana et al., (2022)	The Effectiveness of STEM-Based Android-Based Learning Media on Students' Critical Thinking Skills	Learning media based on Android and employing a STEM approach successfully enhances students' critical thinking abilities, as evidenced by a significant N-gain of 0.77. The evaluation and conclusion sections demonstrate the most significant improvement in students' analytical thinking skills. The findings indicated that Android-based learning media with a STEM approach effectively enhance students' critical thinking abilities.
20	Halim et al., (2023)	Effect of environmental factors on students' interest in STEM careers: The mediating role of self-efficacy	Students' confidence in their own abilities (self-efficacy) plays a central role in linking external influences, such as family support, media exposure, and learning experiences beyond school, to their interest in pursuing STEM careers. While in-school learning experiences did not show a significant effect, media and informal learning proved effective in increasing students' self-efficacy and interest. These findings confirm the importance of strengthening students' STEM learning experiences and STEM self-efficacy through meaningful STEM learning experiences outside the formal classroom to promote interest in STEM careers.
21	Wang et al., (2021)	Promoting STEM Learning through an Interdisciplinary Video Project	Explores the effectiveness of interdisciplinary video projects in enhancing STEM learning in higher education. Through collaboration among students from different disciplines, the initiative promotes the development of critical thinking, problem-solving, and communication skills. The results show that this approach not only deepens students' understanding of STEM concepts but also increases their motivation and engagement in the learning process. Thus, integrating interdisciplinary video projects can be an effective strategy for enriching STEM learning experiences in academic settings.

Discussion

Effect of STEM-based Learning Media in Improving Students' Science Literacy

Using STEM-based learning media has a substantial impact on improving students' science literacy, particularly their ability to make sense of and use scientific concepts in everyday situations. STEM-based media integrates a cross-disciplinary approach to science, technology, engineering, and

mathematics, simultaneously honing critical thinking, problem-solving, and evidence-based decision-making skills. Research shows that the application of project-based STEM learning media can effectively improve science literacy by engaging students in designing, testing, and evaluating scientific solutions to real-world problems (Duo & Ishak, 2024).

STEM media that are designed interactively and contextually also encourage students to understand the relationship between scientific concepts in everyday life. For example, through the development of interactive multimedia equipped with Android-based visualisation and Augmented Reality, students can understand science concepts more concretely, thereby improving their science literacy (Irfana et al., 2022; Sakdiah et al., 2023). Other studies confirm that the use of STEM-based media, such as digital physics modules and manipulative teaching aids, can significantly improve the ability to understand and apply science concepts (Melita et al., 2023; Sulistyawati et al., 2021). Furthermore, science literacy is not limited to conceptual aspects; it also involves the ability to make scientific arguments and evaluate information. STEM-based media, such as educational videos resulting from collaborations between students in science and digital media, have been proven effective in improving understanding and communication of complex scientific concepts (Wang et al., 2021). In addition, research shows that the use of contextualised STEM multimedia, such as interactive media with healthy food or energy themes, can help students relate science to their surrounding environment, thereby increasing engagement and understanding (Khairani et al., 2023).

Additional support comes from a meta-analysis that found STEM-based learning approaches have a significant influence on improving scientific literacy, especially when combined with project-based learning models and specially designed student worksheets (LKPD) (Azizahwati et al., 2023; Agustin et al., 2022). The integration of STEM media in the form of modules, Android applications, and animated videos has also been shown to improve aspects of digital literacy, an important part of digital-era science literacy (Kurniawan et al., 2023; Lafifa & Rosana, 2023).

Thus, based on these studies' results, STEM-based learning media play an important role in improving students' science literacy through interactive, contextual, and applicable learning. This media not only improves conceptual understanding but also develops scientific thinking and digital literacy skills, both of which are highly relevant to addressing the challenges of the 21st century.

Characteristics of Effective STEM-based Learning Media in the Context of Science Learning

The characteristics of effective STEM-based learning media in the context of science learning have several key elements that are interconnected to support students' overall science literacy. Effective media must integrate elements of Science, Technology, Engineering, and Mathematics into a learning approach that is contextual, interactive, and supports 21st-century skills. One of the main characteristics is the active involvement of students in the learning process through challenging, problem-based projects or activities relevant to real life. STEM learning media that use a project-based approach have been proven to significantly improve students' scientific identity and science learning outcomes (Duo & Ishak, 2024).

The effectiveness of STEM media is also strongly influenced by aspects of interactivity and technological accessibility. The use of interactive media based on Android and Augmented Reality (AR) has been proven to improve students' critical thinking skills and mastery of science concepts, with high validity and effectiveness across multiple trials (Irfana et al., 2022; Sakdiah et al., 2023). Interactive multimedia has also shown high effectiveness in developing 21st-century literacy and skills, with an emphasis on contextually relevant content that is easily accessible to students and teachers (Widya et al., 2024). Furthermore, STEM media designed with systematic development models such as 4D and ADDIE demonstrate high validity and practicality and have a positive impact on student learning outcomes. For example, the development of digital media such as the digital calorimeter and Lectora Inspire led to a significant increase in students' mastery of concepts and higher-order thinking skills (Melita et al., 2023; Kurniawan et al., 2023).

The integration of manipulative elements or home-based kits is also considered important in strengthening the practical application of science concepts, with high validity in terms of content and design, and received positive responses from students (Zulirfan & Yennita, 2022; Sulistyawati et al., 2021). Furthermore, the effectiveness of STEM media in improving higher-order thinking skills (HOTS) has been confirmed through a meta-analysis that showed large effect sizes for indicators

such as problem-solving and critical thinking, with LKPD and modules being the most effective (Azizahwati et al., 2023). Other research supports the idea that STEM media that include visual and audio elements, such as educational videos and animations, also have a significant impact on improving students' communication skills, digital literacy, and interest in science learning (Wang et al., 2021; Lafifa & Rosana, 2023).

Thus, effective STEM learning media in science learning are characterised by the integration of real-life context, a project-based approach, the utilisation of interactive technology, the strengthening of higher-order thinking skills, and high instructional design validity. Such media play a crucial role in holistically and sustainably improving students' science literacy.

Factors Influencing the Successful Implementation of STEM-based Learning Media

A range of internal and external factors influences the successful implementation of STEM-based learning media in schools. One key factor is teachers' readiness and competence in designing and implementing STEM media effectively. Teachers with knowledge, positive attitudes, and skills in an interdisciplinary approach will be better able to optimise learning media to improve students' understanding of science (Nurfadilla et al., 2022). In addition, teacher training and technical support in using STEM media are also important for optimal implementation (Hamdu et al., 2021). The next factor is the design and characteristics of the STEM media itself. Media designed using the ADDIE or Design-Based Research approach, and with high validity and practicality scores from experts and users, tend to be more successfully implemented in learning. For example, media-based manipulatives, interactive modules, and digital applications such as STEMATIK and Geomath Room have proven effective and practical in primary and secondary school settings (Hazima et al., 2024; Wijayanti et al., 2023).

The learning environment also determines success. Research shows that family factors, learning experiences outside school, and the availability of supporting facilities, such as internet access and digital devices, greatly influence the effectiveness of STEM learning, especially in online or home-based learning conditions (Halim et al., 2023; Zulirfan & Yennita, 2022). Success is also largely determined by the relevance of local context and by curriculum integration. Media that link STEM learning to everyday themes, such as renewable energy, hydropower, or environmental projects, have been shown to increase students' engagement in learning while helping them better understand concepts and think more critically (Sulistyawati et al., 2021; Lestari & Muhajir, 2024). Finally, institutional support and school policies are important factors. Schools that support learning innovation, provide time for teaching experiments, and have a collaborative culture among teachers will be more successful in adopting STEM-based learning media. In this context, systematic implementation, such as the use of digital platforms during the pandemic or the adoption of a structured STEM thematic curriculum, also contributes to the program's success (Yusuf et al., 2021; Artobatama et al., 2023).

Thus, the successful use of STEM-based learning tools in schools results from a complex interaction among teacher competence, media design, support for the learning environment, relevance to local context, and educational institution policy.

CONCLUSION

STEM-based learning media have a significant role in improving students' science literacy at various levels of education. It has been proven to strengthen understanding of scientific concepts, develop critical thinking skills, and improve students' digital literacy through contextual, interactive, and project-based learning approaches. Characteristics of effective STEM media include the use of technology such as interactive multimedia, augmented reality, and digital applications that are relevant to real life, as well as valid and practical instructional design. The successful implementation of this media is strongly influenced by teacher competence, support for the learning environment, relevance to the local context, and support from educational institution policy. Therefore, integrating STEM-based learning media into educational practices is not only an innovative solution but also a strategic necessity to equip students with comprehensive, relevant science literacy to address the challenges of the 21st century. Future research is recommended to explore the long-term impact of

STEM-based learning media on students' science literacy across diverse educational levels and cultural contexts, and to develop adaptive digital tools that support personalised learning and teacher facilitation.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to all those who contributed to the completion of this study. The authors would like to thank their colleagues and supervisors who provided valuable advice, counsel, and support during the writing of this article. The author would also like to thank all the researchers and practitioners whose work was referenced. Finally, the author would like to thank family and friends for their encouragement in completing this article.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (433-443)
Online: http://journal.uny.ac.id/index.php/jitp

Student perceptions of the use of VR to introduce Malang local tourism and culture

Helmi Muzaki[1] *, Gatut Susanto[1], Kusubakti Andajani[1], Afiyahtun Isnaeni[1], Ilham Akhsani[2], Thilip Kumar Moorthy[3]
[1] Universitas Negeri Malang, Indonesia.
[2] Politeknik Baja Tegal, Indonesia.
[3] Tunku Abdul Rahman University of Management and Technology, Malaysia.
*Corresponding Author. E-mail: helmi.muzaki.fs@um.ac.id

ARTICLE INFO

Article History
Received:
19 August 2025;
Revised:
8 October 2025;
Accepted:
29 Oktober 2025;
Available online:
31 December 2025.

Keywords
Learning experience; Local culture; Local tourism; Virtual reality

ABSTRACT

This study investigates students' perceptions of the use of Virtual Reality (VR) as a learning medium for introducing tourism and local culture in Malang. This research employed a quantitative descriptive design involving 23 first-semester students selected through purposive sampling. Data were collected using a Likert-scale questionnaire (1–5) consisting of 17 statements that measured learning effectiveness, educational value, tourism introduction, cultural understanding, and the development of knowledge and skills. The results indicate that students demonstrated highly positive perceptions of VR implementation, with an overall mean score of 4.34. The highest score was obtained in the aspect of local tourism introduction (M = 4.46), followed by local cultural understanding (M = 4.41) and learning effectiveness (M = 4.37). These findings show that VR provides an immersive and engaging learning experience that enhances students' understanding of tourism and local culture. Therefore, it is recommended that educators and institutions further integrate and develop VR as an innovative technology-based learning strategy to enrich educational practices.

How to cite:
Muzaki, H., et al., (2025). Student perceptions of the use of VR to introduce malang local tourism and culture. *Jurnal Inovasi Teknologi Pendidikan, 12*(4). 433-443. https://doi.org/10.21831/jitp.v12i4.88958

INTRODUCTION

The advent of new information and communication technologies has transformed specific industries, such as education or even tourism. One of the leading modern technologies in both of these fields is VR. Unlike traditional means of relaying information, such as pictures and videos, as Bailenson (2018) stated, VR can take users into a virtual world that offers more engaging interactivity. In education, users are provided with endless opportunities to learn and discover the diverse parts of the world. Similarly, in tourism, people can visit beautiful tourist attractions and cultural landmarks without truly having to travel.

Malang City has great potential to promote the richness of local culture and lesser-known tourist destinations. The natural beauty of Mount Bromo and Teluk Asmara Beach, along with the cultural diversity of the East Javanese people, reflected in their traditions, cuisine, and daily life, are important assets that can be utilised as contextual learning resources. In this context, Virtual Reality (VR) technology offers new opportunities to provide more immersive learning experiences,

especially for students from remote geographic areas who cannot visit these locations in person (Rachmad, 2024).

However, the use of VR technology in education and local tourism still faces several challenges. One important aspect to consider is how students perceive the effectiveness of this technology in supporting the learning process and promoting local tourism. As a generation relatively familiar with digital technology, students have the potential to be primary users of VR. However, their level of acceptance and perception of the tangible benefits of VR in enhancing the learning experience remain underexplored (Zhang, 2024).

In addition to user perception, other challenges relate to accessibility and technical constraints in using VR. Hardware limitations, virtual content quality, and users' understanding of VR technology can affect its effectiveness as a learning medium and a tool for introducing tourism (Shehade & Stylianou-Lambert, 2020; Yang, 2024). Therefore, this study aims to explore students' perceptions of the use of VR in learning and in introducing local tourism in Malang City, while also examining the extent to which this technology can enrich their learning experiences in Indonesian, deepen their understanding of local culture, and enable them to explore tourist destinations more contextually.

VR offers excellent opportunities to introduce local tourism more engagingly and comprehensively. With VR, local tourism can be introduced virtually to a broader audience, giving them a first-hand experience even if they cannot physically visit (Tanvir, 2022). This certainly has the potential to increase interest in local tourism in Malang City, which, in turn, will have a positive impact on the local economy and cultural preservation.

Previous studies related to VR have been conducted, including Alizadeh & Hawkinson (2021), who examined a case study of the use of VR in tourism schools; Yung & Khoo-Lattimore (2019) & Tussyadiah et al., (2018), who examined VR in tourism; Malik et al., (2024), who examined VR for Education; Mura et al., (2017), who examined students' perceptions of the authenticity of tourism with VR; Wang et al., (2020) & Muzaki et al., (2025), who examined the impact of VR on intercultural competence, Shadiev et al., (2020), & Harris & Seo (2024), who examined students' perceptions of the use of VR in cultural learning. Based on previous research, there is no specific research on how students view the use of VR for studying tourism and local culture. Therefore, this study investigated new students' perceptions of VR's use to introduce Malang's tourism and local culture.

METHOD

This study uses quantitative descriptive statistics to reveal perceptions and explain reasons through thematic data analysis. Data were collected primarily through a questionnaire comprising 17 closed-ended statements, rated on a Likert scale. A descriptive design is well-suited for perception studies to yield rich, detailed quantitative answers (Sugiyono, 2020). The sample size was considered appropriate because the study focused on analysing user perceptions and experiences rather than on making statistical generalisations. A total of 23 participants falls within the recommended range for evaluative research and limited trials of learning media, where a sample size of 10–30 participants is suggested to assess the feasibility and acceptability of educational technology (Hertzog, 2008; Sukserm, 2024). The sample was obtained through purposive sampling based on the following criteria: (1). new students (semester 1), (2). not yet familiar with the local Malang culture and tourism.

Research Instrument

The research instrument was a questionnaire consisting of two parts. The first part included closed-ended questions (Likert scale 1-5) in Table 1 that measured perceptions of the VR experience, learning effectiveness, potential for cultural introduction, and skill development.

Table 1. Research Instrument

Code	Statements	1	2	3	4	5
X1	The use of VR in learning makes the subject matter more straightforward to comprehend.					
X2	Using VR provides a more engaging learning experience.					
X3	I feel more involved in the learning process when VR is used.					
X4	Using VR makes me feel closer to the material being studied.					
X5	With VR, I can learn complex topics more simply.					
X6	The use of VR in education can improve learning quality compared to traditional methods.					
X7	I find it easier to understand abstract concepts using VR.					
X8	VR provides a more realistic experience of exploring tourist destinations in Malang City.					
X9	I feel more interested in visiting tourist attractions in Malang after using VR.					
X10	VR can offer various tours of Malang in a more interactive way than just watching pictures or videos.					
X11	I feel more connected to Malang's tourist attractions through the VR experience.					
X12	I find it easier to imagine difficult-to-reach tourist attractions in VR than in written descriptions or pictures.					
X13	Using VR provides a deeper understanding of Malang's history and culture.					
X14	The use of VR in introducing local tourism in Malang has increased my interest in learning more about local culture.					
X15	VR can provide a more in-depth experience of Malang's natural beauty and culture.					
X16	VR helps me develop my Indonesian language skills through more realistic experiences.					
X17	The VR experience enhanced my understanding of Malang's culture and tourist attractions.					

1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

Instrument Validity and Reliability

Internal reliability was assessed using Cronbach's alpha to evaluate the consistency of the questionnaire items. The test results obtained using SPSS version 27 showed an alpha value of 0.966, indicating very high reliability. This value suggests that the questionnaire items consistently measure a single central construct, namely, students' perceptions of the use of VR in learning about local tourism and culture. The high alpha value may also be influenced by the relatively large number of items and the homogeneous characteristics of the respondents, who were early VR users. Since this is a pilot study, the reliability results provide an initial indication of the instrument's consistency. Further testing with a larger sample, such as factor analysis, is recommended in future studies to more comprehensively examine the construct structure.

Data Collection Technique

Data for this study were collected using an online questionnaire created in Google Forms. The instrument was distributed to respondents through digital platforms such as WhatsApp, which was considered effective in reaching new students. Respondents independently completed the questionnaire, with an estimated completion time of ±15 minutes. The use of online questionnaires is considered appropriate and efficient, given the characteristics of the respondents as part of the digital-native generation, namely an age group that has grown up with digital technology and is accustomed to accessing information and communicating via the internet (Prensky, 2001). Students from this generation tend to prefer online survey systems that are flexible, easily accessible via mobile devices, and time-efficient. Research findings by Evans and Mathur (Prensky, 2001) indicate that the advantages of online surveys include broad accessibility, cost efficiency, and ease of real-time data analysis. Additionally, online distribution enables flexible data collection without

geographic constraints, which is particularly suitable for a student population. Automatically recorded responses also facilitate efficient tabulation and quantitative data processing.

Data Analysis Techniques

This study employed descriptive quantitative analysis to examine closed-ended data collected via a Likert-scale questionnaire. Quantitative data were analysed using SPSS to identify trends in students' perceptions of VR as a learning medium for introducing local culture and tourism. The analysis procedures included calculating the mean score for each questionnaire item, tabulating frequencies and percentages to examine the distribution of responses across categories, and interpreting the results based on predetermined score intervals, as shown in Table 2.

Table 2. Criteria for Interpreting Student Response Questionnaire Scores

No.	Score Range	Perception Category
1	1.00 – 1.80	Very Low
2	1.81 – 2.60	Low
3	2.61 – 3.40	Medium
4	3.41 – 4.20	High
5	4.21 – 5.00	Very High

RESULTS AND DISCUSSION

Results

The results section presents findings based on five key aspects used to evaluate students' perceptions of the use of VR in introducing Malang local tourism and culture.

Student Perception of the Influence of VR Media in Learning

Student perceptions of the influence of VR media on learning were measured using four statement items that assessed the effectiveness, engagement, learning experience, and immediacy of understanding the material through VR. The following are students' perceptions of the influence of VR media on learning, as shown in Table 3.

Table 3. Descriptive Statistics Student Perception of the Influence of VR Media in Learning

Statistical Data	Code				Average
	X1	X2	X3	X4	
Number of Participants	23	23	23	23	
Minimum	3	3	4	3	3.25
Maximum	5	5	5	5	5
Sum	98	103	100	101	100.5
Mean	4.26	4.48	4.35	4.39	4.37
Standard Deviation	.113	.124	.102	.137	0.119

Student Perception of the Effectiveness of VR in Education

Table 4 presents descriptive statistics on students' perceptions of VR's effectiveness in education.

Table 4. Descriptive Statistics Perception of the Effectiveness of VR in Education

Statistical Data	Code			Average
	X5	X6	X7	
Number of Participants	23	23	23	
Minimum	3	3	3	3
Maximum	5	5	5	5
Sum	99	97	95	97
Mean	4.30	4.22	4.13	4.22
Standard Deviation	.132	.125	.120	0.129

Student Perception of VR Effectiveness in Introducing Malang Local Tourism

The following are descriptive statistics on students' perceptions of VR's effectiveness in promoting local tourism in Malang, as shown in Table 5.

Table 5. Descriptive Statistics Perception of VR Effectiveness in Introducing Malang Local Tourism

Statistical Data	Code					Average
	X8	X9	X10	X11	X12	
Number of Participants	23	23	23	23		
Minimum	3	3	3	3	3	2.8
Maximum	5	5	5	5	5	5
Sum	102	102	104	100	105	102.6
Mean	4.43	4.43	4.52	4.35	4.57	4.46
Standard Deviation	.123	.164	.124	.135	.123	0.1338

Student Perceptions of the Effectiveness of VR in Introducing Malang Local Culture

The following presents descriptive statistics on students' perceptions of the effectiveness of VR in introducing Malang local culture (see Table 6).

Table 6. Descriptive Statistics Perception of the Effectiveness of VR in Introducing Malang Local Culture

Statistical Data	Code			Average
	X13	X14	X15	
Number of Participants	23	23	23	
Minimum	3	3	3	3
Maximum	5	5	5	5
Sum	103	100	101	101.3
Mean	4.48	4.35	4.39	4.41
Standard Deviation	.124	.119	.137	0.127

Student Perceptions on the Influence of VR on Knowledge and Skills Development

The following presents descriptive statistics on students' perceptions of VR's influence on knowledge and skill development (Table 7).

Table 7. Descriptive Statistics: Student Perceptions on the Influence of VR on Knowledge and Skills Development

Statistical Data	Code		Average
	X16	X17	
Number of Participants	23	23	
Minimum	3	3	3
Maximum	5	5	5
Sum	94	102	98
Mean	4.09	4.43	4.26
Standard Deviation	.139	.123	0.131

Discussion

Student perceptions of the effect of VR media on learning had an average score of 4.37, indicating a Very High level of perception. Several aspects were measured. First, the use of VR helped in understanding the material, with a score of 4.26. This shows that most students realise the benefits of VR in narrowing the knowledge gap regarding complex concepts. This is in accordance with the findings of Chatain et al., (2023), who stated that VR facilitates a more effective understanding of digital representation manipulation through sensorimotor stimulation with abstract concepts. Additionally, learners can manipulate the virtual world, which increases their retention of abstract concepts (MavRomatis et al., 2025). Second, VR provides increased learner engagement and

an improved teaching experience, earning a score of 4.48, the highest among all items. Since this finding shows that there is a significant motivational appeal to VR technology in teaching, it further strengthens the claims made by Menin et al., (2018) and Bowman & McMahon (2007), who showed that learning with VR technology is more motivating than traditional methods. Third, participants felt more emotionally engaged. The average score of 4.35 shows why most users feel that incorporating VR allows for greater attention, making it easier for educators who want user-centred education to achieve successful outcomes by offering an engaging, demonstrative environment (Radianti et al., 2020). This illustrates that VR increases student engagement through its high interactivity, thereby encouraging deeper learning. Fourth, the application of VR technology provides a sense of closeness to the material being studied, with a score of 4.39 on the measurement scale. This shows that VR can foster an affective bond among learners and educational content. Huang et al., (2010) note that feelings of closeness to the subject matter are an important indicator of experiential learning, which is best supported by VR technology. These outcomes show that students have a positive perception of VR technology and greatly appreciate its effectiveness in improving the quality of the learning process.

Students' perceptions of VR's effectiveness in education show positive scores, averaging 4.22 and falling into the Very High category. Specifically, VR can teach complex topics more simply, with a score of 4.30. This shows that students feel the real benefits of VR-based learning experiences. Cognitively, VR can reduce cognitive load (Chao et al., 2017). This is done by transforming abstract concepts into visualisations that can be observed and manipulated directly. Second, the use of VR in education can improve the quality of learning compared to traditional methods, by a score of 4.22. This outcome reflects students' belief in the superiority of technology-based approaches over conventional approaches. The use of VR significantly improves learning outcomes, especially in education (Leong et al., 2024), engineering (Ishihara & Komori, 2016), and medicine (Mazurek et al., 2019; Wenli Lian, 2023). The quality of learning improves because VR provides experience-based learning that activates more visual, kinesthetic, and even emotional cognitive pathways. Third, respondents found it easier to understand abstract concepts utilising VR, with a score of 4.13, which falls into the "High" category. Although slightly lower than the other two indicators, this score still indicates students' recognition that VR can transform abstract concepts into concrete experiences. This aligns with constructivist theory, which states that individuals actively construct knowledge through direct experience (Jumaat et al., 2017; Llanas, 2018).

Student perceptions of VR's effectiveness in introducing local tourism in Malang are positive, with an average score of 4.45. First, VR is considered to provide a more realistic experience for exploring Malang's tourist destinations, with a score of 4.43. This indicates that VR can provide an immersive experience, enabling users to feel a virtual presence that is close to reality (Chang & Suh, 2025; Guerra-Tamez, 2023). This positions it as a superior learning medium compared to traditional learning media. Second, students showed an increased interest in visiting Malang after engaging in VR, with a score of 4.43. These findings are consistent with those of Kieanwatana & Vongvit (2024) and Alkhalifah et al., (2025), who demonstrated that VR experiences can directly enhance user interest in visiting tourist sites. VR offers both visual and emotional stimulation, thereby heightening users' interest and curiosity about tourist destinations viewed through VR. Third, the introduction of tourism via VR was deemed more effective than videos or images, with a score of 4.53. According to Hamilton et al., (2021), VR offers advantages over image or video media because VR users actively explore virtual environments. This cannot be achieved with passive media such as images and videos. Fourth, students had a greater emotional bond with tourist attractions in Malang, scoring 4.35. This shows that VR can foster an emotional connection with the tourist attractions. With VR, users feel as if they are in or visiting a place, which can create an emotional connection. Huang et al., (2010) and Skard et al., (2021), reported that strong emotional involvement is significant for forming a psychological bond with a place. Emotional bonds can also directly influence students' decisions to visit tourist destinations. Fifth, VR makes it easier for users to imagine tourist attractions, with a score of 4.57. This strengthens Han et al., (2013), statement that VR functions as a very effective simulation medium for introducing destinations that have been described or are less well known to the public.

The use of VR technology to introduce Malang's local culture has shown significant effectiveness in increasing students' understanding, interest, experience, and involvement with it**.** Three question items were used to measure students' perceptions of VR's effectiveness in introducing Malang's local culture, yielding the following results. First, the understanding of Malang's culture and history gained through VR was 4.48. This shows that students felt VR technology helped deepen their understanding of Malang's local culture, and that using VR as a learning medium allows them to access historical and cultural information in a more engaging way than traditional methods, such as reading textbooks or watching documentaries. As stated by Slater & Wilbur (1997), one significant advantage of using virtual presence-based teaching aids is the ability to build a strong sense of presence during learning, so that the learning experience can be felt directly rather than just read or seen. Using VR allows students to participate in 3D cultural tour simulations. Another advantage is that, by using VR, users can access aspects of culture that are difficult to reach through conventional media. For example, VR can take students on a simulated historical or cultural journey in Malang that is physically impossible, such as visiting historical sites located far inland or introducing local cultures rarely exposed.

Second, the application of VR technology in local tourism learning for students from other regions increased their interest in uncovering local culture, with an average score of 4.35. This finding indicates that students are more inclined to learn about culture after a direct VR experience. This also implies that VR plays an important role not only as a tool for transmitting information but also for increasing one's interest in culture. This phenomenon is not surprising because the possibilities offered by VR technology are much more comprehensive in terms of interactivity than in traditional classroom settings. The interactivity provided by VR, where users can choose which objects to explore and teleport, easily motivates students and draws their attention much better than traditional methods. Tussyadiah et al., (2018) have shown through research how the immersive experience provided by VR greatly increases motivation to learn, especially in the context of tourism and cultural education.

Third, VR can provide a more in-depth experience of Malang's natural and cultural scenery, earning a score of 4.39. This shows that students feel that they have deepened their experience of Malang's nature and culture using VR technology. Students can virtually visit local tourist attractions in Malang and experience a unique cultural atmosphere without leaving their homes. VR provides a more precise, detailed projection of the environment and culture.

The study's results showed that across two questions measuring students' perceptions of the influence of VR Media on learning, the average score was above 4.26, indicating a very high perception category. The results are as follows.

First, VR helps respondents develop Indonesian language skills through more real experiences, with a score of 4.09. These results indicate that students perceive VR as beneficial for improving their Indonesian-language skills. VR provides direct experiences that facilitate language learning in an authentic, contextual way. The use of VR allows students to interact with various real communication situations, for example, by speaking in simulated situations at tourist attractions or in social situations involving Indonesian.

In the context of language learning, contextual learning theory states that learning in relevant and realistic contexts can strengthen understanding and application of knowledge (Bransford et al., 2000). With VR, students not only learn vocabulary and sentence structures, but also feel and interact in real-world situations involving Indonesian. This makes language learning more interesting and memorable, as well as more relevant to real life.

Second, the experience of using VR technology significantly enhanced students' understanding of Malang's culture and tourist destinations. A score of 4.43 reflects this. Students felt that VR provided an opportunity to explore various aspects of culture and tourist attractions more closely, even though they were not physically present at the location. Unlike media such as images or videos, VR provides a more immersive experience, as if they were actually there.

This study has several limitations that should be noted. First, the research was conducted with a relatively small sample drawn from a single student group, limiting the generalizability of the findings to other educational contexts. Second, the study focused mainly on students' perceptions of

VR as a learning medium without directly measuring objective learning outcomes or long-term understanding of local culture and tourism. Other influential factors, such as learning motivation, instructional design quality, and digital readiness, were also not examined in this study. Given these limitations, it is recommended that future research use larger, more diverse samples to yield more representative results. Additionally, subsequent studies could incorporate objective performance measures and additional variables, such as motivation, engagement, and instructional design factors, to provide a more comprehensive understanding of VR's effectiveness in supporting cultural and tourism education.

CONCLUSION

Based on the findings, students perceive Virtual Reality (VR) as an effective learning medium for introducing Malang's local tourism and culture, as its immersive features help learners gain a more realistic, contextual understanding, even without direct physical visits. This conclusion answers the research objective by confirming that VR supports students' comprehension and engagement in learning about local cultural and tourism content. Based on these findings, integrating VR into educational practice can serve as an operational strategy to enhance local wisdom-based learning, strengthen cultural literacy, and promote innovative approaches to cultural preservation through technology-supported instruction. However, because the study was limited to a small sample and focused primarily on students' perceptions rather than measurable learning outcomes, the conclusions should be interpreted cautiously. Future educational practice should combine VR with structured instructional design and evaluation methods. At the same time, further research is suggested to involve broader participant groups and experimental approaches to more comprehensively assess the effectiveness of VR in cultural and tourism education.

ACKNOWLEDGEMENT

The researcher would like to thank the State University of Malang for funding this research through the Faculty of Literature's decentralised research funding program.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (444-454)
Online: http://journal.uny.ac.id/index.php/jitp

Interactive mobile learning to improve computational thinking and achievement in digital systems courses

Anak Agung Gde Ekayana[1] *, Desak Made Dwi Utami Putra[1], I Gde Wawan Sudatha[2]
[1] Institut Bisnis dan Teknologi Indonesia, Indonesia.
[2] Universitas Pendidikan Ganesha, Indonesia.
***** Corresponding Author. E-mail: gungekayana@instiki.ac.id

ARTICLE INFO

Article History
Received:
21 August 2025;
Revised:
27 October 2025;
Accepted:
1 November 2025;
Available online:
31 December 2025.

Keywords
Computational thinking; Digital systems; Educational technology; Learning achievement; Mobile learning

ABSTRACT

The digital era has fundamentally transformed classroom instructional approaches, shifting the focus from completing subject matter to meaningful student engagement and active knowledge construction. Grounded in constructivist learning theory and principles of computational thinking, this study aims to examine the effectiveness of interactive mobile learning as a technology-enhanced instructional innovation in digital systems education. The innovation integrates multimedia, interactivity, and problem-based activities to support students' analytical and algorithmic reasoning. A quasi-experimental method was employed, involving 112 students enrolled in a digital systems course, with a nonequivalent control group pretest–posttest design. Data were analysed through multivariate analysis of covariance, independent T-tests, and N-gain analysis to evaluate learning effectiveness. The results revealed significant effects, both partial and simultaneous, with the experimental group consistently outperforming the control group. T-test findings indicated statistically significant differences between students using interactive mobile learning and those receiving conventional instruction. Furthermore, N-gain analysis showed improvements of 0.65 in computational thinking skills and 0.70 in learning achievement, categorised as medium to high gains. These findings confirm that interactive mobile learning effectively enhances learning outcomes. Therefore, it is recommended that educators integrate interactive mobile learning into digital systems instruction to foster students' computational thinking and academic achievement.

How to cite:
Ekayana, A.A.G, Putra, D. M. D. U., & Sudatha, I. G.W. (2025). Interactive mobile learning to improve computational thinking and achievement in digital systems courses. *Jurnal Inovasi Teknologi Pendidikan, 12*(4), 444-454. https://doi.org/10.21831/jitp.v12i4.89321

INTRODUCTION

The evolution of learning in the digital era has profoundly transformed higher education. Artificial intelligence (AI) technology, learning analytics, and educational platforms and mobile devices promote more personalised, adaptive, and interactive learning (Behar et al., 2020; Fernández & Roa Martín, 2022; Ma & Li, 2021). Mobile technology supports learning systems that can adjust materials and levels of difficulty based on individual needs, while educational technologies ranging from Learning Management Systems (LMS), web-based simulations, to augmented/virtual reality provide means of visualisation and practice that were previously difficult to realise in a conventional classroom environment (Angraini et al., 2024; Anwar et al., 2024; Masruroh et al., 2024). The integration of this technology not only expands access and flexibility but also opens up opportunities

for feedback, continuous assessment, and increased student engagement through a more contextual and meaningful learning experience (Su'uga et al., 2020; Subiki et al., 2023). This development is highly relevant to courses with a high level of abstraction, as it can bridge the gap between theoretical concepts and practical application (Muskhir et al., 2025).

Digital Systems courses play a central role in computer systems engineering education because they provide the conceptual foundation for understanding digital logic, network design, and hardware architecture underlying modern computing systems (Anwar et al., 2024; Tasrif et al., 2024). However, the abstract and conceptual nature of topics such as logic operations, number system transformations, and circuit simulations often creates significant learning difficulties when instruction relies primarily on lectures and textbooks (Jevanda BS et al., 2024). These challenges are reflected in relatively low student achievement and persistent difficulties in developing computational thinking skills, compounded by limited laboratory practice time, heterogeneous prior knowledge, and insufficient interactive learning resources capable of delivering immediate feedback and dynamic visualisation (Ardiansyah et al., 2024; Ekayana et al., 2024; Pratiwi & Santyasa, 2021); (Angraini et al., 2024; Bunyakul, 2022; Komalawardhana, 2021). Such conditions indicate an urgent need for instructional innovations that can bridge conceptual abstraction with experiential learning in digital systems education.

The development of mobile devices and digital pedagogy opens up opportunities to address these problems (Sari & Dantes, 2024). Interactive mobile learning combines multimedia, real-time simulations, adaptive quizzes, and feedback mechanisms that students can access anytime. The use of mobile phones and tablets that are already commonly owned by students supports the innovation of a mobile-based learning media that can increase accessibility, support independent learning, and provide a more concrete learning experience through logic animations, network simulations, and interactive exercises (Muskhir et al., 2025; Wiweka et al., 2024). Pedagogically, the interactive mobile learning approach is aligned with active learning theory and constructivism. Students become the leading actors in building knowledge through digital asset manipulation, authentic problem-solving, and reflection on the process (Budyastuti & Fauziati, 2021; Masgumelar & Mustafa, 2021). Good instructional design makes use of scaffolding from tutorials to open-ended tasks to support the transition from basic understanding to implementation. The development of innovations in the learning realm must consider the close relationship with the syllabus, learning objectives, and assessment instruments so that learning activities can be measured in their contribution to learning outcomes (Ardiansyah et al., 2024; Wu et al., 2022).

Although interactive mobile learning offers promising solutions to these instructional challenges, several important research gaps remain. Empirical studies that jointly examine its effects on computational thinking and academic achievement in Digital Systems courses are still scarce. In addition, validated, context-specific instruments for measuring computational thinking in digital systems learning are limited, and many existing mobile applications are poorly aligned with course syllabi or targeted competencies. These limitations limit the availability of strong evidence on the effectiveness of syllabus-integrated mobile learning, underscoring the need for focused research in this area.

A review of recent empirical studies suggests that interactive mobile learning has substantial potential to enhance higher education learning outcomes and advanced cognitive skills. The findings indicate that mobile learning integration can positively influence academic achievement and higher-order thinking processes (Sazen, 2020). Simulation-based mobile (SiM) learning environments have been shown to partially substitute laboratory experiences when designed with appropriate usability, task validity, and alignment with professional competencies (Juera, 2024). Furthermore, mobile learning interventions demonstrate positive effects on the development of computational thinking components such as problem decomposition, pattern recognition, and algorithmic reasoning compared with conventional instruction (Connolly et al., 2021). Nevertheless, prior studies generally examine these effects in isolation and rarely focus on Digital Systems courses with integrated curriculum alignment. This limitation highlights the novelty of the present study, which investigates a syllabus-integrated interactive mobile learning model and evaluates its combined effects on computational thinking skills and academic achievement.

Mobile learning, interactive media innovation in the Digital Systems course, is not only directed to present material more attractively but also to form a learning environment that encourages students to develop computational thinking skills systematically. Through support for digital circuit simulations, logic animation, and adaptive quizzes, students not only passively learn concepts but also actively engage in analysis, problem decomposition, algorithmic solution design, and evaluation. In addition, integrating media design with learning outcomes and curriculum assessments ensures that improving students' computational skills aligns with improving academic achievement, making this innovation potentially significant for the quality of learning. Based on this description, this study aims to evaluate the influence of the application of interactive mobile learning that is directly integrated into the learning process of Digital Systems courses. The evaluation focuses on two main aspects: improving computational thinking skills and learning achievement.

METHOD

The research subjects came from pre-formed classes, so complete randomisation was not possible. Therefore, the research design used was a Nonequivalent Control Group Pretest-Posttest design. The sample determination resulted in six classes, which were divided into experimental and control groups (Pramashela et al., 2023; Pratiwi & Santyasa, 2021). The class division is shown in Table 1.

Table 1. Research Design

No.	Group	Pre-test	Treatment	Post-test
1	Control Class	O_1	X_1	O_2
2	Experimental Class	O_3	X_3	O_4

The design of this study compared the effects of treatment between the experimental and control groups by measuring the variables studied before and after the treatment (Suliyanthini & Yulianur, 2023). Both groups were given initial tests to measure computational thinking skills and learning achievement before treatment. The experimental group consisted of 56 students drawn from Classes B, D, and E, who participated in learning activities using interactive mobile learning features. Meanwhile, the control group included 56 students from Classes A, C, and F who received direct instruction. The intervention was implemented over one lecture cycle, comprising six meetings.

The research instruments in this study consisted of two variables. First, a computational thinking test is developed to measure four indicators: problem decomposition, pattern recognition, abstraction, and algorithmization. Second, a learning achievement test that focuses on measuring students' cognitive abilities, including the levels of concept, analysis, understanding, and application in the Digital System course. The research instruments are shown in Table 2 and Table 3.

Table 2. Indicators of Computational Thinking

No.	Indicators of Computational Thinking	Explanation
1	Dekomposisi	Ability to break down complex problems into simpler parts
2	Pattern recognition	Ability to identify regularity or similarities in data and processes
3	Abstraksi	Ability to focus on relevant information while ignoring unimportant details
4	Algoritma	Ability to design systematic steps to solve problems

Table 3. Learning Achievement Instruments

No.	Learning Achievement Instruments	Competence
1	Describe the main differences between combination logic sets and sequential logic sets in digital systems design.	C2 - Understanding
2	Describe the central role of basic logic gates (AND, OR, NOT) and how they combine to form a simple digital circuit.	C2 - Understanding
3	Make an illustration and explain the working mechanism of shift registers in digital systems, including one example of its application.	C3 - Application

No.	Learning Achievement Instruments	Competence
4	Describe the stages of the process of converting analogue signals to digital signals in digital systems, and mention the role of ADC components.	C2 - Understanding
5	Arrange the steps of creating a counter and clock-based circuit that turns on the LEDs alternately at every 1-second interval.	C3 -Application
6	Analyse the differences in the communication characteristics of synchronous and asynchronous data in digital systems, and explain their effect on transmission performance.	C4 - Analyze
7	Explain the concept of interruption in a digital system that uses a microcontroller, then give an example of its use in an automated sensor-based system.	C4 - Analyze
8	Design a flowchart or process narrative of a digital system that activates an automatic fan based on temperature readings from sensors.	C6 - Create
9	Describe the procedure for connecting a 16x2 LCD module to a digital circuit and explain how the data is transmitted until it appears on the screen.	C3 - Application
10	Describe the steps of determining the type of logic circuit or processor that is appropriate for a digital control system, along with the technical reasons for the choice.	C5 - Evaluate

The computational thinking and learning achievement test instruments were subjected to validity and reliability testing to ensure their measurement adequacy. Content validity was evaluated using Aiken's V method through expert judgment by three specialists, yielding coefficients of 0.88 for the computational thinking instrument and 0.92 for the learning achievement instrument (Muskhir et al., 2025). Internal consistency reliability was assessed using Cronbach's Alpha, which produced a coefficient of 0.79, indicating acceptable reliability. Only instruments that satisfied the validity and reliability criteria were used for data collection.

The collected data were analysed using multivariate analysis of covariance, independent T-tests, and N-gain analysis to examine differences in learning outcomes between groups (Ekayana et al., 2025). These three formulas were used to provide more comprehensive results from the implementation of the learning methods applied to each class (Tafakur et al., 2023). These three analysis techniques were used to draw more convincing conclusions about whether differences resulted from the implementation of the learning methods (Syahri et al., 2021). Prior to hypothesis testing, prerequisite analyses were conducted to determine the suitability of parametric statistical techniques. These analyses included tests of normality and homogeneity of variance.

RESULTS AND DISCUSSION

Results

The research process involved six classes, divided proportionally into two groups: three in the experimental group and three in the control group. The learning process was carried out six times according to the predetermined treatment plan. Before the learning implementation, all participants were given a pretest that had undergone validity and reliability testing. The descriptive results of each research variable are shown in Table 4.

Table 4. Descriptive Summary of Computational Thinking Results and Learning Achievement

Model	Variabel	Mean	Standard deviation	Minimum Score	Maximum Score	Range
K-1 (Classes using *interactive mobile learning*)	Computational Thinking	60,68	21,490	22	98	76
	Learning Achievement	59,77	24,508	20	100	80
K-2 (Classes using conventional methods	Computational Thinking	54,32	16,402	20	84	64
	Learning Achievement	53,21	20,980	20	100	80

Based on the results of the descriptive analysis in Table 4, the average value of computational thinking in the experimental class (K-1) was 60.68, while the control class (K-2) reached only 54.32. In terms of learning achievement, K-1 achieved an average of 59.77, higher than K-2, which achieved 53.21. This average difference shows that the application of an interactive mobile learning model has a greater impact than conventional learning methods. The descriptive results provide an initial analysis indicating that the classes provided by Interactive Mobile Learning during the learning process yield superior results compared to those from the direct instructional method.

The prerequisite tests were conducted before hypothesis testing and included normality and homogeneity analyses. These tests were performed to determine the suitability of the data for MANCOVA analysis. The normality test evaluated whether the students' pretest and posttest scores were normally distributed, while the homogeneity test assessed whether the variances between the experimental and control groups were equal, ensuring valid comparisons. The results showed that the data satisfied the assumptions of normality and homogeneity. A detailed summary of these findings is presented in Table 5, Table 6, and Table 7.

Table 5. Results of the Prerequisite Test for Data Normality

Variabel	**Learning**	**Kolmogorov-Smirnova Minimum Score**		
		Statistic	**df**	**Sig.**
Computational Thinking Learning Achievement	Classes using interactive mobile learning	0.95	112	0.241
	Classes using conventional methods	0.75	112	0.162
	Classes using interactive mobile learning	0.68	112	0.127
	Classes using conventional methods	0.72	112	0.133

Table 6. Results of the Prerequisite Test for Homogeneity of Variance

Levene	**df_1**	**df_2**	**Sig.**
Computational Thinking	1	110	0.153
Learning Achievement	1	110	0.280

Table 7. Results of the Prerequisite Test for Variance between Groups

Box's M	**F**	**Sig.**
11.765	1.854	0.098

The data were tested for normality using the Kolmogorov-Smirnov test, as shown in Table 5. The test results showed that the computational thinking variable in the experimental group with interactive mobile learning had a significance value of 0.241. In contrast, the control group with conventional methods obtained a value of 0.162. Meanwhile, the learning achievement variable in the experimental group showed a significance value of 0.127, and in the control group, 0.133. All of these values are above the significance level of $\alpha = 0.05$, so it can be concluded that the distributions of pretest and posttest data for both variables are in the standard distribution category. Furthermore, the variance homogeneity test was performed to assess the uniformity of data dispersion across groups. Based on the homogeneity results shown in Table 6, the significance values for the computational thinking variable and greater learning achievement were 0.153 and 0.280, respectively, which are not significant at the 0.05 level, indicating no significant difference in variance between the experimental and control groups.

Since the study involves more than one variable, the prerequisite analysis is conducted not only on each variable separately but also on combinations of variables. Therefore, variance homogeneity testing was conducted jointly across groups on the variables of computational thinking and digital system learning achievement. This test is carried out using Box's Test of Equality of Covariance Matrices, which evaluates the similarity of the variance-covariance matrices across the groups being compared. The results of Box's M analysis in Table 7 show a significance value of 0.098, which is greater than the significance level of $\alpha = 0.05$. This indicates that the variance-covariance matrix across groups is not different, so the homogeneity assumption of covariance is met.

Table 8. Results of the Multivariate Analysis of Covariance Test are Simultaneously

Effect	F Coefficient	Sig.
Intercept	5966.746	0.000
	5966.746	0.000
	5966.746	0.000
	5966.746	0.000
Learning Methods	34.797	0.000
	34.797	0.000
	34.797	0.000
	34.797	0.000

Based on the results of the simultaneous statistical analysis in Table 8, the F coefficient was 34.797, with a significance value (Sig.) = 0.000 (< 0.05). These results show that learning method variables significantly influence the dependent variables simultaneously. In addition, the Intercept value also shows an F coefficient of 5966.746 with a significance of 0.000. This emphasises that interactive media-based learning methods can significantly influence variables in computational thinking and learning achievement.

Table 9. Results of the multivariate analysis of covariance

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Learning Methods	Computational Thinking	3774.188	1	3774.188	45.348	.000
	Learning Achievement	3165.178	1	3165.178	17.973	.000
Pretest Computational Thinking	Computational Thinking	87.524	1	87.524	1.052	.307
	Learning Achievement	6.375	1	6.375	.036	.849
Pretest Learning Achievement	Computational Thinking	.054	1	.054	.001	.980
	Learning Achievement	.219	1	.219	.001	.972
Error	Computational Thinking	8905.403	107	83.228		
	Learning Achievement	18843.840	107	176.111		
Total	Computational Thinking	624872.000	112			
	Learning Achievement	674972.000	112			
Corrected Total	Computational Thinking	13925.714	111			
	Learning Achievement	22271.107	111			

The multivariate analysis of covariance results presented in Table 9, describe the effect of the independent variable on the dependent variables after controlling for the covariates. The learning method showed a statistically significant effect on computational thinking skills, $F(1, 107) = 45.348$, $p < .001$, and on learning achievement, $F(1, 107) = 17.973$, $p < .001$. These findings indicate that differences in instructional methods were associated with differences in students' computational thinking and learning achievement. In contrast, the covariate pretest of computational thinking did not show a significant effect on computational thinking skills, $F(1, 107) = 1.052$, $p = .307$, or on learning achievement, $F(1, 107) = 0.036$, $p = .849$. Similarly, the covariate pretest of learning achievement did not significantly affect computational thinking skills, $F(1, 107) = 0.001$, $p = .980$, or learning achievement, $F(1, 107) = 0.001$, $p = .972$. These results suggest that students' initial scores did not significantly influence posttest outcomes after controlling for the treatment. The Tests of Between-Subjects Effects further support that the observed differences in outcomes were primarily associated with the learning method rather than baseline ability.

Table 10. Independent Samples T-Test Test Results

	T-test for Equality of Means					
	t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Computational	6.474	110	.000	11.714	8.129	15.300
Thinking	6.474	99.916	.000	11.714	8.124	15.304
Learning	4.392	110	.000	10.893	5.977	15.808
Achievement	4.392	109.116	.000	10.893	5.977	15.809

The Independent Samples t-test is performed to ensure that the difference in different learning outcomes is statistically significant. This analysis aimed to evaluate the extent to which interventions were given to both groups. A summary of the test results is presented in Table 10. The Independent Samples t-test showed a statistically significant difference between the experimental and control groups. The computational thinking variable produced a t-value of 6.474 with 110 degrees of freedom (df) and a significance value (p) of 0.000 (< 0.05). In contrast, the learning achievement variable obtained a t-value of 4.392 with a df of 110 and a significance value (p) of 0.000 (< 0.05). These results confirm that the learning intervention applied to the experimental group had a significant effect compared to the direct instruction method used in the control group.

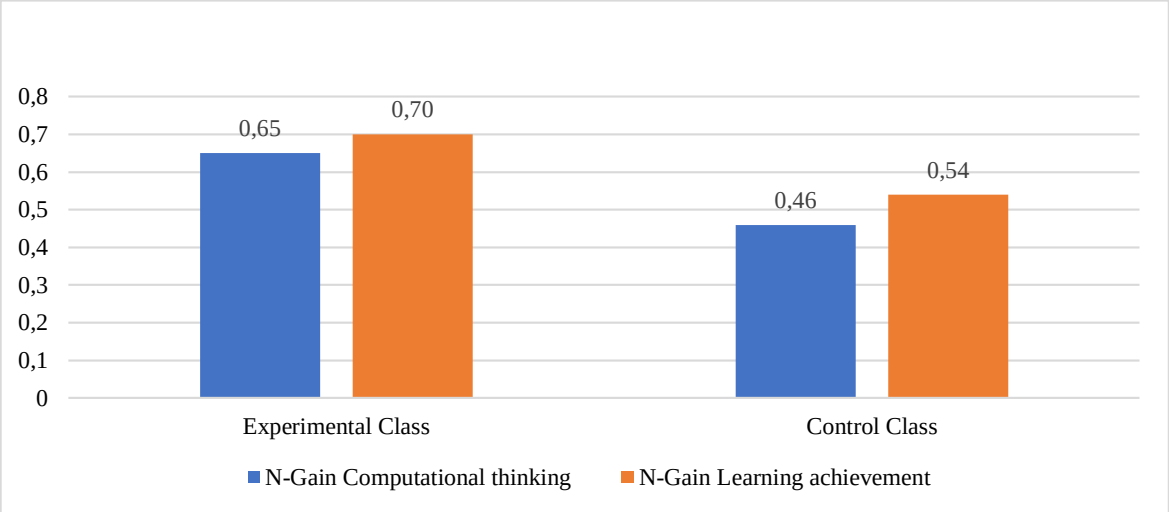

Figure 1. N-gain Comparison Results for each Class and Variable

Based on the N-Gain analysis shown in Figure 1, the increase in computational thinking ability and learning achievement was greater in the experimental class than in the control class. In the computational thinking variable, the initial average value of the experimental class (41.64) increased to 79.71 in the final measurement, resulting in an N-Gain of 0.65, which was classified as a moderate to high increase. In contrast, the control class increased from 40.64 to 68, with an N-Gain of 0.46, placing it in the moderate improvement category. The learning achievement variable for the experimental class showed a significant increase from an initial average score of 37.75 to 81.78 at the final measurement, with an N-Gain of 0.70, indicating significant improvement. Meanwhile, the control class only increased from 35.53 to 70.89, resulting in an N-Gain of 0.54, which is classified as a medium category. Based on the results of the N-Gain analysis, the intervention, which used interactive learning media in the experimental class, was shown to make a more significant contribution to improving computational thinking skills and learning achievement than conventional learning methods in the control class.

Discussion

The findings of this study show that the application of interactive learning media has a significant positive impact on improving computational thinking skills and student learning achievement when compared to conventional learning methods. This increase is consistent with the results of the Independent Samples t-test and the N-Gain, which show that interactive media-based interventions can strengthen computational thinking skills and learning achievement. These results can be explained through the theoretical framework of learning media, which states that interactive media allows multimodal learning, where the integration of text, visuals, animation, and interactivity can facilitate dual coding and reduce excessive cognitive load (Criollo-C et al., 2024; Perez-Poch et al., 2021; Sudiarti et al., 2023). This approach aligns with constructivist learning principles, in which learners actively build knowledge through interaction with content and contextually designed learning environments (Budyastuti & Fauziati, 2021; Masgumelar & Mustafa, 2021; Subiki et al., 2023).

Several recent studies align with the present findings and reinforce the role of interactive mobile learning in enhancing higher-order thinking and academic performance. Prior research has demonstrated that interactive media in STEM education can significantly improve students' problem-solving and advanced thinking skills compared with lecture-based instruction (Zhuang et al., 2021). Mobile-based and project-oriented learning environments have also been shown to increase students' motivation, self-efficacy, and academic achievement in engineering contexts (Ariza, 2023). Evidence indicates that mobile learning interventions effectively support the development of students' critical thinking skills across educational levels. In a related study, Rahman et al., (2025) reported that mobile-based interactive media significantly improved learning outcomes and student engagement in digital learning environments (Rahman et al., 2025). The present study extends these findings by providing empirical evidence within the specific context of Digital Systems courses, demonstrating that syllabus-integrated interactive media can simultaneously enhance computational thinking skills and learning achievement. This consistency with prior research suggests that interactive mobile learning contributes to more engaging and cognitively supportive learning environments that foster deeper conceptual understanding.

The integration of interactive learning media into digital system lectures can be an effective strategy to improve the quality of learning in computational thinking and learning achievement. This finding provides a logical consequence for educators: the need to design teaching materials that are not only oriented to the delivery of information but also encourage active student interaction and deep reflection (Pratama et al., 2023). In addition, learning media developers are expected to utilise the principles of multimedia learning and user experience so that the media produced is not only visually appealing but also effective in facilitating meaningful learning (Zulfa, 2025). Although the research has implications for improving computational thinking skills and learning achievement, it also has limitations that need to be considered. First, the study covered only one course and involved a limited sample of two classes, so generalising the results to a broader learning context required further research. Second, the relatively short duration of the intervention did not fully allow for evaluating the long-term impact of interactive media on knowledge retention. Further research should explore the implementation of interactive media across courses with varying topic coverage and levels of complexity, as well as with extended intervention periods, to assess the sustainability of their impact on knowledge and skill retention. Additional measures of variables such as learning motivation, collaborative skills, and digital literacy should also be considered to obtain a more comprehensive picture of the effectiveness of interactive media.

CONCLUSION

Based on the findings, it can be concluded that the implementation of interactive mobile learning media is efficacious in improving students' computational thinking skills and learning achievement in Digital Systems courses. Students who learned through mobile-based interactive media achieved superior outcomes compared with those receiving conventional instruction, indicating that mobile interactive learning is a practical instructional approach for enhancing cognitive skills and academic performance. These findings imply that integrating interactive mobile media into higher education teaching practices can support more student-centred, engaging, and adaptive learning environments. Therefore, lecturers are encouraged to incorporate interactive mobile learning into their instructional strategies to foster active learning and strengthen students' higher-order thinking skills. Educational institutions are advised to support this implementation through adequate infrastructure, professional development, and institutional policies that promote digital learning innovation. Future research should examine longer-term implementation across diverse courses and levels of content complexity to evaluate the sustainability of learning gains and explore the integration of interactive mobile learning with other instructional approaches, such as project- and problem-based learning.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (455-467)
Online: http://journal.uny.ac.id/index.php/jitp

Enhancing learning activity and learning outcomes in the electrical installation course using augmented reality

Hasrul Bakri[1] *, Mukhlisin[1], Indra Sukma[1], Muhira Dzar Faraby[2]
[1] Universitas Negeri Makassar, Indonesia.
[2] Politeknik Negeri Ujung Pandang, Indonesia.
* Corresponding Author. E-mail: hasrulbakri@unm.ac.id

ARTICLE INFO

Article History
Received:
22 August 2025;
Revised:
15 October 2025;
Accepted:
27 November 2025;
Available online:
31 December 2025.

Keywords
Augmented reality;
Interactive learning;
Learning engagement;
Learning outcomes

ABSTRACT

Student engagement and learning outcomes are two interrelated aspects that determine the effectiveness of the teaching and learning process. This study aimed to analyse the impact of Augmented Reality (AR)-based learning on student engagement and academic achievement compared to conventional instruction. The research employed a quasi-experimental design with an experimental and a control class. Student engagement was assessed through cognitive, affective, and psychomotor dimensions, while learning outcomes were measured using a post-test. The findings revealed that AR-based learning significantly improved student engagement across all domains, with average scores of 91.35% in the cognitive domain, 87.54% in the affective domain, and 90.04% in the psychomotor domain, all surpassing the success threshold of >75%. Conversely, the control class achieved only 79.67% in the cognitive domain, while the affective (66.62%) and psychomotor (69.34%) domains fell short of the expected standard. Similarly, the experimental group demonstrated higher academic performance, with a mean post-test score of 91.21, compared to 66.46 in the control group. These results indicate that AR-based learning not only fosters active student participation but also enhances academic achievement. The study implies that integrating innovative, technology-enhanced strategies in higher education is essential for promoting holistic learning that prepares graduates for professional and digital-era challenges.

How to cite:
Bakri, H., et al., (2025). Enhancing learning activity and learning outcomes in the electrical installation course using augmented reality. *Jurnal Inovasi Teknologi Pendidikan, 12*(4), 455-467. https://doi.org/10.21831/jitp.v12i4.89327

INTRODUCTION

Student activeness is one of the key indicators of successful learning in higher education (Li & Xue, 2023). Active students tend to demonstrate higher cognitive, affective, and psychomotor engagement, enabling them to internalise concepts more effectively (Liu, 2024; Pratomo et al., 2025). In the context of technical education, particularly in the Electrical Installation course, student engagement is crucial because the subject matter is not only conceptual but also demands practical skills that require spatial and procedural understanding (Ariza, 2023). Without active participation, students risk experiencing a gap between theoretical mastery and the practical skills needed in the workplace (Porat & Ceobanu, 2024). Sustained engagement in such courses also fosters problem-solving skills, critical thinking, and adaptability, which are essential competencies in the rapidly

evolving technical industry (Tsai et al., 2024). Furthermore, active involvement enhances collaborative learning experiences, allowing students to develop teamwork and communication skills that are vital for professional success (Ruiz-Rojas et al., 2024).

Unfortunately, conventional teaching methods still primarily focus on one-way delivery of material through lectures and limited demonstrations (Özden et al., 2024). This often results in students becoming passive recipients of information, with little involvement in the learning process. In fact, research has shown that active student engagement can enhance motivation to learn, knowledge retention, and problem-solving skills (Castillo et al., 2023). In vocational and technical education, active participation also affects students' work-readiness and adaptability to technological developments in industry (Alhawiti, 2023). Moreover, insufficient opportunities for hands-on learning may hinder the development of practical competencies critical to professional performance (DelaTorre-Díaz et al., 2025). Consequently, there is a growing need to adopt innovative pedagogical approaches that promote deeper involvement and interaction throughout the learning process (Chao & Li, 2025).

AR has emerged as an innovative technology that can facilitate increased student engagement (Zhang et al., 2024). AR enables the integration of three-dimensional virtual objects into the real world, allowing students to directly interact with simulations of electrical equipment and circuits visually and interactively (Mukhlisin et al., 2025). Studies developing the AR Laboratory Environment (ARLE) have shown that students become more active in exploring concepts, independently experimenting with electrical installation configurations, and demonstrating improved technical skills (Kovalev et al., 2025; Palada et al., 2024).

However, the effectiveness of AR in enhancing student activeness has not been entirely consistent (Kim & Choi, 2025). A study used the application as a laboratory preparation tool and found that although students reported high engagement, there was not always a significant improvement in learning outcomes or long-term motivation compared to traditional methods (Goh, 2025). Several studies have also indicated that the novelty effect of technology may boost activeness only at the initial stage, but this tends to decline over time if not supported by appropriate instructional design (Cicconi, 2024; Rayan & Watted, 2024).

Furthermore, previous research has tended to focus more on measuring students' perceptions of AR than on objectively assessing activity through indicators such as participation analysis, interaction frequency, or initiative in completing tasks (Mohamad & Husnin, 2023). The scarcity of studies linking AR use to objectively measured student activity creates a clear research gap (Kim & Choi, 2025). Moreover, very few studies have combined AR with a robust experimental design, such as the Solomon Four-Group Design, which can isolate the effect of technology on student activity from other factors, such as pretest effects or initial motivation (Mukhlisin et al., 2025).

In response to these conditions, the present study is designed to examine the effectiveness of AR in improving student engagement in the Electrical Installation course at the higher education level. By employing the Solomon Four-Group experimental design, this research aims to provide stronger empirical evidence on the impact of AR on student engagement, while offering an innovative instructional strategy relevant to technical and vocational education in the digital era. Furthermore, the study investigates how increased student engagement contributes to improved learning outcomes, thereby providing a more comprehensive understanding of the pedagogical value of AR in technical education.

METHOD

This study employed an experimental method using the Solomon Four-Group Design. This design was selected because it allows for the examination of the effects of AR technology on enhancing students' learning activity in the electrical installation course, while simultaneously controlling for potential pretest effects that may influence the results (Jdaitawi et al., 2022). In this design, students were divided into four groups: an experimental group with a pretest, a control group with a pretest, an experimental group without a pretest, and a control group without a pretest (Ssemugenyi, 2023). The experimental groups received instruction using AR-based learning, whereas the control groups participated in conventional learning without AR. The study was

conducted across four universities offering electrical engineering programs during the 2024/2025 academic year. The population consisted of all students enrolled in the electrical installation course, and the sample was selected via cluster random sampling based on available class sections, totalling 139 students, as shown in Table 1.

Table 1. The Solomon Fourth Group Design Experimental

No.	Group	Pretest	Treatment	Posttest
1	Experiment 1	O_1	X_1	O_2
2	Control 1	O_3		O_4
3	Experiment 2		X_2	O_5
4	Control 2			O_6

The study was conducted across four universities offering electrical engineering programs during the 2024/2025 academic year. The population consisted of all students enrolled in the electrical installation course. Experiment 1 was conducted at University A with 34 students, Control 1 at University B with 35 students, Experiment 2 at University C with 35 students, and Control 2 at University D with 35 students. The experimental groups received AR-based learning interventions, whereas the control groups participated in conventional instruction without AR.

Data collection techniques use observation and tests in the form of descriptions. The research instruments comprised two main components: a student learning activity observation and a cognitive test. The learning activity observation was designed to assess student engagement during the learning process. To ensure the accuracy and objectivity of the collected data, the observation process was conducted by three independent observers who had been trained to use the observation instrument consistently. In contrast, the cognitive test was used to assess students' learning outcomes and examine the relationship between engagement levels and academic achievement. The data from observations of student activities were analysed by describing the stages of learning using Formula 1 (Purwanto, 2013).

$$\text{NP} = \frac{R}{SM}\ x\ 100 \quad (1)$$

Information:
NP: Per cent Value
R: Score Acquisition
SM: Ideal Maximum Score of Test Points
100: Fixed Number

Student learning engagement is considered successful when it meets the criterion of achieving a score of 75% or higher. This benchmark serves as a standard to evaluate the extent to which students are actively involved in the learning process. In this context, learning can be regarded as both effective and of high quality if all, or at least the majority (75%), of students demonstrate active participation across the three dimensions of engagement: cognitive, affective, and psychomotor. These dimensions reflect not only students' intellectual involvement but also their emotional commitment and practical participation during the learning process. To systematically assess this engagement, an observation instrument was employed, as presented in Table 2, which provides detailed indicators for measuring student activity throughout the learning sessions.

Table 2. Student Activity Observation Instrument

Aspects	Description of Observable Behaviour	Indicator
Cognitive	1. The student prepares for class by bringing learning resources and opening relevant materials before the session begins. 2. The student remains attentive throughout the class, avoids distractions, and follows the lecturer's instructions.	1. Bringing learning materials and preparing notes. 2. Maintaining focus on the lecturer's explanation.

Aspects	Description of Observable Behaviour	Indicator
	3. The student actively seeks or proposes solutions when facing challenges in understanding the lesson content.	3. Attempting to find solutions when encountering difficulties.
	4. The student connects the concepts learned to practical experiences or workplace situations.	4. Relating lesson content to real-life applications.
	5. The student shows enthusiasm in participating in class and responds positively to the lecturer's questions.	5. Demonstrating interest and motivation in learning.
	6. The student participates actively in group discussions or collaborative tasks.	6. Actively engaging in group work.
Affective	7. The student completes assigned tasks within the given deadlines.	7. Completing assignments on time.
	8. The student demonstrates interest in further exploring the lesson content outside of class sessions.	8. Showing willingness to learn beyond class hours.
	9. The student actively asks questions or shares opinions during class discussions.	9. Asking questions or expressing opinions.
	10. The student can demonstrate skills or procedures in accordance with the lecturer's instructions.	10. Performing learned skills during class activities.
Psychomotor	11. The student proactively engages in learning activities without waiting for the lecturer's instructions.	11. Voluntarily engaging without prompts.
	12. The student directly and actively participates in practical or laboratory-based learning activities.	12. Actively participating in hands-on activities.

Learning outcome data were first subjected to preliminary assumption testing, including the Kolmogorov–Smirnov test for normality and Levene's test for homogeneity of variance. Once the statistical assumptions were met, further analysis was conducted using Analysis of Covariance (ANCOVA) and Independent Samples t-test to determine the effect of AR on student engagement and its relationship with improved learning outcomes. If the results of the ANCOVA show a significance value (p) < 0.05, this can be interpreted as indicating a statistically significant difference between the experimental group and the control group after accounting for the influence of initial ability (Wu et al., 2025). Meanwhile, for the Independent Sample t-Test, if the significance value (p) < 0.05, it can be concluded that the two groups exhibit a statistically significant difference in learning achievement (Bagheri et al., 2025). The test instrument for the electrical installation course's learning outcomes is shown in Table 3.

Table 3. Electrical Installation Course Learning Outcome Test Instrument

No.	Question
Q1	Explain the definition of a simple household electrical installation and identify its main components.
Q2	Draw a single-line diagram representing the electrical installation of a house with two bedrooms, one living room, and one kitchen.
Q3	State and explain the function of an MCB (Miniature Circuit Breaker) in a simple household electrical installation.
Q4	Describe the procedure for installing a single-pole switch to control the lighting in the living room.
Q5	Explain the differences in application between NYA, NYM, and NYY cables in a simple household electrical installation.
Q6	List the safety inspection steps that must be taken before starting work on a simple household electrical installation.
Q7	Calculate the total electrical power consumption (in watts) for a house equipped with six 15-watt LED lamps, two 60-watt electric fans, and one 150-watt refrigerator. Also, determine the total current required if the supply voltage is 220 V.
Q8	Explain the concept of grounding in a simple household electrical installation and its function.
Q9	Identify common causes of electrical faults in a simple household electrical installation and describe appropriate troubleshooting measures.

No.	Question
Q10	Provide the routine maintenance steps necessary to ensure that a simple household electrical installation remains safe and efficient.

RESULTS AND DISCUSSION

Results

The results of this study focus on two main aspects: the analysis of students' activity levels during the learning process and the analysis of improvements in students' learning outcomes following the intervention. The analysis of student activeness was conducted to determine the extent to which the implementation of AR-based learning could foster students' cognitive, affective, and psychomotor engagement during the Electrical Installation course. Student engagement is recognised as a critical indicator of successful learning, as active participation in the learning process is believed to strengthen conceptual understanding.

Implementation of AR in the Electrical Installation Course

The implementation of AR in the Electrical Installation course was carried out through a series of structured stages designed to maximise students' interaction with the learning materials and instructional objects. In the initial stage, the instructor introduced the AR application and provided a brief demonstration on how to scan markers, manipulate three-dimensional objects, and access simulation features. This approach ensured that all students possessed a basic understanding of how to operate the application before engaging in the core learning activities.

During the learning process, AR was used as the primary medium to help students understand electrical concepts that are often difficult to grasp when delivered solely through two-dimensional images on the whiteboard or in textbooks. By utilising AR, students were able to visualise electrical circuits in three dimensions, zoom in on and rotate components, and observe the interrelationships between the installation's elements more clearly. The AR visual representation enabled students to independently explore circuit structures and gain a comprehensive understanding of each component's function, as shown in Figure 1 below.

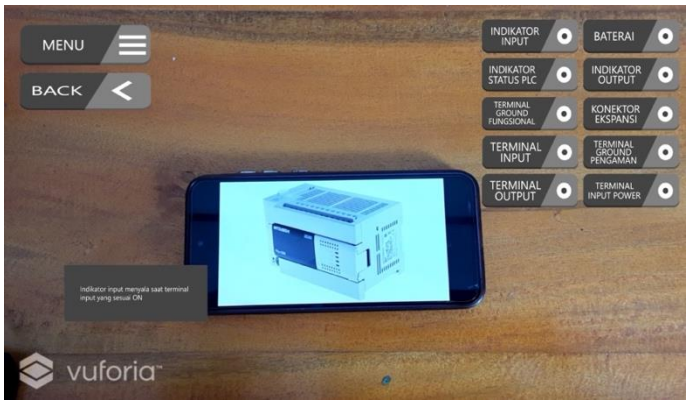

Figure 1. Student Activity Data in Experiment 1 and Control 1

Student Activeness Analysis

The data on student activity were collected through direct observation during the Electrical Installation course sessions. Three trained observers carried out the observations to ensure consistency in the assessment process. The observation instrument was developed based on three main dimensions of student activeness: cognitive, affective, and psychomotor. The observations were conducted continuously during each learning session, both for the experimental group, which utilised AR, and for the control group, which employed conventional teaching methods. All observation data were compiled, analysed, and presented as bar charts to facilitate comparison between groups. The

presentation of data in Figure 2 aims to provide a visual representation of the differences in student activeness levels across the three measured dimensions for each group.

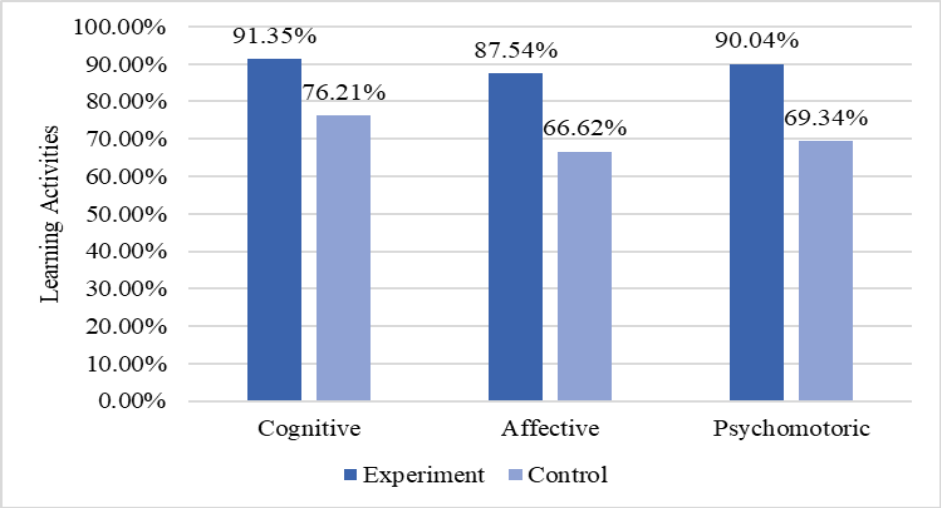

Figure 2. Student Activity Data in Experiment 1 and Control 1

Based on the graph, there is a noticeable difference in student learning activities between the experimental and control classes across the three dimensions: cognitive, affective, and psychomotor. In the cognitive dimension, students in the experimental class achieved a learning activity level of 91.35%, which was higher than that of the control class (76.21%). This finding indicates that the instructional approach implemented in the experimental class was more effective in encouraging critical thinking, conceptual understanding, and problem-solving skills. In the affective dimension, the experimental class reached 87.54%, while the control class achieved only 66.62%. This suggests that students in the experimental class demonstrated greater motivation, enthusiasm, and positive attitudes toward the learning process compared to their counterparts. In the psychomotor dimension, the experimental class again showed superior outcomes, with 90.04% compared to 69.34% in the control class. This result reflects the effectiveness of the experimental learning model in fostering practical skills, active participation, and hands-on engagement.

Overall, the findings reveal that the experimental class demonstrated a consistently high level of learning engagement, with scores exceeding 85% across all measured dimensions. This performance not only surpassed the minimum benchmark of >75% but also indicates that the instructional approach in this class fostered optimal levels of student activity. In contrast, the control class showed relatively weaker results, particularly in the affective and psychomotor dimensions, with scores remaining below the success threshold. These results show that the learning method implemented in the experimental class was more effective at promoting comprehensive student engagement across cognitive, affective, and psychomotor domains than the conventional instructional approach.

Analysis of Improving Student Learning Outcomes

Before examining differences in students' learning outcomes between the experimental and control groups, preliminary assumption tests were carried out to ensure that the data met the required statistical assumptions. These preliminary tests included a normality test to determine whether the learning outcome data were normally distributed and a homogeneity-of-variance test to verify the equality of variances across groups. The normality test was performed using the Kolmogorov–Smirnov method, while the homogeneity of variance was assessed using Levene's Test, which can be seen in Table 4.

Table 4. Normality Test Results for Experimental 1 and Control 1

	Group	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig.
Learning Outcomes	Pretest Experiment$_1$	.137	34	.108

Group	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Posttest Experiment$_1$	.128	34	.174
Pretest Control$_1$	.143	35	.068
PosttestControl$_1$	.140	35	.079

The results of the Kolmogorov–Smirnov normality test presented in Table 4 indicate that all significance (Sig.) values for both the pretest and posttest data in the experimental and control groups are above 0.05. This finding suggests that the distribution of learning Outcome data across all groups meets the assumption of normality. With this assumption fulfilled, the learning outcome data are deemed appropriate for further analysis using parametric statistical tests to more accurately examine differences in learning achievement between the experimental and control groups. Subsequently, the same normality test was conducted on the learning outcome data for Experimental Class 2 and Control Class 2. The testing procedure used the Kolmogorov–Smirnov method on the first set of groups.

Table 5. Normality Test Results for Experimental 2 and Control 2

	Group	Kolmogorov-Smirnov[a]		
		Statistic	df	Sig.
Learning Outcomes	Posttest Experiment$_2$	.135	35	.108
	Posttest Control$_2$	.131	35	.138

The results of the Kolmogorov-Smirnov normality test presented in Table 5 indicate that the significance (Sig.) value for the Posttest Experimental 2 group is 0.108, and for the Posttest Control 2 group is 0.138, both of which exceed the threshold of 0.05. These findings suggest that the distribution of learning outcome data for both groups meets the assumption of normality. With this assumption satisfied, the learning outcome data from the Experimental 2 and Control 2 groups are deemed suitable for further analysis using parametric statistical tests, thereby allowing a valid and reliable examination of differences in learning achievement between the groups.

After the normality test was conducted and the data were confirmed to follow a normal distribution, the next step prior to performing parametric statistical analysis was to examine the homogeneity of variances. The purpose of this test is to determine whether the variances or the spread of data across the groups being compared are statistically equivalent. The homogeneity of variance was assessed using Levene's Test, which tests whether the variances differ significantly across groups. If the significance value (Sig.) exceeds 0.05, the variances are considered homogeneous, and the assumption of homogeneity is deemed to be met. The results of the homogeneity test are presented in Table 6.

Table 6. Results of the Homogeneity Test

Levene Statistic	df1	df2	Sig.
.27	3	139	.839

Based on the results of the homogeneity of variance test using Levene's Test, as presented in the table, a significance value (Sig.) of 0.839 was obtained. This value is substantially higher than the critical threshold of 0.05, indicating that there is no significant difference in variance among the groups compared in this study. Therefore, it can be concluded that the learning outcome data across the four groups exhibit homogeneous or equal variances. Homogeneity of variance is a fundamental assumption that must be met before performing parametric statistical analyses such as ANCOVA or the Independent Samples t-test. When this assumption is satisfied, the results of inferential analyses are considered more valid and unbiased, as equal group distributions ensure the integrity of statistical comparisons.

Subsequently, after confirming that the learning outcome data for the Experimental 1 and Control 1 classes met the assumptions of normality and homogeneity of variance, an ANCOVA was conducted. This analysis aimed to examine differences in learning outcomes between the two groups while controlling for prior ability (pretest) as a covariate. By employing ANCOVA, the analysis was

expected to provide a more accurate depiction of the effect of the Augmented Reality-based instructional intervention on students' learning outcomes, controlling for variations in their initial abilities.

Table 7. ANCOVA Analysis Results for Experimental 1 and Control 1

Source	Type III Sum of Squares	Df	Mean Square	F	Sig.
Corrected Model	11227.184[a]	3	3742.395	344.327	.000
Intercept	270.389	1	270.389	24.878	.000
Pretest	594.593	1	594.593	54.707	.000
Group	9795.852	2	4897.926	450.644	.000
Error	706.468	65	10.869		
Total	438779.000	69			
Corrected Total	11933.652	68			

Based on the analysis presented in Table 7, the significance value for the Group factor is 0.000 (< 0.05), indicating a significant difference in learning outcomes between Experimental Group 1 and Control Group 1 after controlling for prior ability (pretest). The Pretest covariate also shows a significance value of 0.000 (< 0.05), suggesting that students' initial abilities significantly influence their learning achievements. The exceptionally high F-value for the Group factor (450.644) indicates a strong effect of the Augmented Reality-based instructional intervention on improving learning outcomes. These findings confirm that integrating Augmented Reality into the Electrical Installation course substantially enhances students' academic performance compared to conventional teaching methods, even after accounting for differences in initial ability.

Following the ANCOVA analysis for Experimental Group 1 and Control Group 1, the next step was to conduct an Independent Samples t-test for Experimental Group 2 and Control Group 2. This test was employed to compare the learning outcomes between the two groups that did not receive a pretest, thereby determining whether there were significant differences in achievement after participating in instruction using different methods. Experimental Group 2 received instruction based on AR, whereas Control Group 2 followed conventional teaching methods. Through this analysis, it is expected that a more precise understanding of AR's effectiveness in enhancing student learning outcomes can be obtained in a context where no initial measure of academic ability is available.

Table 8. Independent T-test Analysis Results for Experimental 2 and Control 2

T	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
27.67	69	.000	28.09	1.015	26.06	30.11
27.60	66.43	.000	28.09	1.017	26.06	30.12

Based on the analysis presented in Table 8, the significance value (Sig. 2-tailed) was 0.000 (< 0.05), indicating a statistically significant difference in learning outcomes between Experimental Class 2 and Control Class 2. The mean difference of 28.09 indicates that students in Experimental Class 2 had substantially higher learning outcomes than those in Control Class 2. The 95% confidence interval for the mean difference ranged from 26.06 to 30.12, entirely above zero, thereby reinforcing the evidence of a genuine treatment effect. The remarkably high t-value (27.67) indicates that the observed difference is not only statistically significant but also demonstrates a strong effect size. These findings suggest that Augmented Reality–based learning makes a significant contribution to improving students' academic performance compared to conventional teaching methods in contexts where no pretest is administered.

Based on the results of data analysis, both through ANCOVA conducted on Experimental Class 1 and Control Class 1, as well as the Independent Sample t-Test performed on Experimental Class 2 and Control Class 2, the findings indicate a significant difference in learning outcomes between the group that received Augmented Reality-based instruction and the group that engaged in conventional learning. This difference demonstrates that integrating Augmented Reality provides a substantial, tangible contribution to enhancing students' academic achievement. The improvement

in learning outcomes is illustrated in the following graph, which presents the differences in mean final scores between the two groups for each test. This is shown in Figure 3.

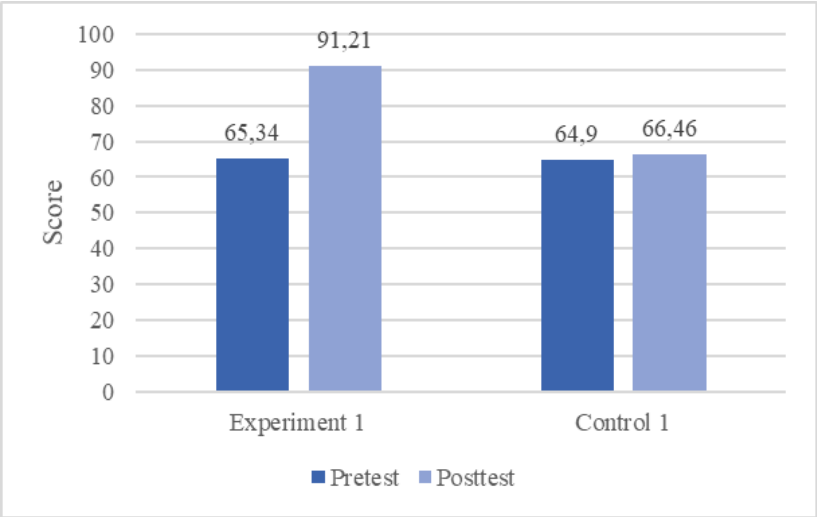

Figure 3. Comparison of Learning Outcomes between Experiment 1 and Control 1

Discussion

The findings of this study indicate that integrating AR into the learning process can effectively address the limitations of conventional teaching methods, which often rely on one-way delivery of material. By presenting content in an interactive and immersive format, AR transforms students from passive recipients into active participants in their own learning. This transformation is crucial in vocational and technical education, where the ability to apply knowledge in real-world contexts is as important as mastering theoretical concepts (Moukhliss et al., 2024; Su et al., 2025). The interactive nature of AR allows students to manipulate virtual objects, explore simulated environments, and receive immediate feedback, thereby fostering a more dynamic and engaging learning atmosphere (Rodríguez-Saavedra et al., 2025).

Moreover, the active engagement facilitated by AR aligns with research suggesting that such involvement enhances learning motivation, knowledge retention, and problem-solving abilities (Neale et al., 2025). In this study, students who received AR-based instruction demonstrated not only higher test scores but also greater enthusiasm for the learning process (Kim & Choi, 2025). The visual and experiential elements of AR appear to stimulate curiosity and sustain attention, enabling learners to process and retain information more effectively (Palada et al., 2024). These findings corroborate earlier work in educational technology that highlights the cognitive benefits of interactive and multimodal learning environments.

From a skills development perspective, AR provides an avenue for bridging the gap between theory and practice (Mansour et al., 2024). The hands-on learning opportunities offered through AR simulations allow students to practice technical procedures in a risk-free environment before applying them in real-world situations (Suhail et al., 2024). This is particularly relevant in vocational and technical education, where practical competence is a core requirement for professional readiness. Through repeated and self-paced practice in an AR environment, students can refine their skills, correct errors, and build confidence, all of which are essential for successful workplace performance (Rodríguez-Abad et al., 2023).

The adaptability fostered by AR-enhanced learning also addresses the industry's demand for graduates who are comfortable with emerging technologies. Exposure to AR tools in an educational context helps students develop not only content-specific skills but also broader technological literacy (Crogman et al., 2025; Mukhlisin et al., 2023; Mukhlisin, Gani, Purnamawati, et al., 2022). As industries continue to evolve toward automation and digital integration, familiarity with advanced tools becomes an asset that enhances employability (Nurhayati et al., 2025; Tzirides et al., 2024). The ability to quickly adapt to new technologies, learned through experiences such as AR-based

learning, supports long-term career growth and resilience in rapidly changing work environments (Poláková et al., 2023).

Additionally, the collaborative potential of AR can be leveraged to promote peer learning and teamwork, both of which are critical in professional settings (Alkhabra et al., 2023). Instructors can design AR activities that require students to work together to solve problems, analyse scenarios, or complete projects, thereby fostering communication, coordination, and shared responsibility (Lorenzis et al., 2024). Such experiences not only reinforce academic content but also build interpersonal skills that are highly valued in the workforce. By embedding collaboration into the AR learning experience, educators can cultivate a more holistic set of competencies in their students (Y. Wu et al., 2023). Then, AR merges theoretical knowledge with practical applications, making it an essential tool for educational advancement (Mukhlisin, Gani, & Purnamawati, 2022).

In summary, integrating AR into teaching and learning directly addresses the shortcomings of traditional lecture-based methods by fostering active participation, enhancing motivation and retention, providing practical skill development, supporting technological adaptability, and encouraging collaborative learning (Egunjobi & Adeyeye, 2024). The results of this study demonstrate that AR can serve as a powerful pedagogical tool in vocational and technical education, offering measurable improvements in learning outcomes and better preparing students for professional success (González et al., 2025). These findings underscore the importance of continued innovation in educational practice, particularly in contexts where hands-on competencies and technological readiness are critical for graduate employability.

CONCLUSION

Based on the findings, it can be concluded that the implementation of AR-based learning significantly enhanced both student engagement and learning outcomes compared to conventional instruction. Student engagement in the experimental class achieved excellent results, with average scores of 91.35% in the cognitive domain, 87.54% in the affective domain, and 90.04% in the psychomotor domain, all exceeding the success threshold of >75%. In contrast, the control class only reached 79.67% in the cognitive domain, while the affective (66.62%) and psychomotor (69.34%) domains remained below the expected standard. This increased engagement was reflected in student achievement, where the experimental group obtained a mean post-test score of 91.21, considerably higher than the control group's mean score of 66.46. These findings demonstrate that technology-enhanced learning not only fosters active participation but also contributes to higher academic achievement. The implications of this study suggest that lecturers and higher education institutions should consider adopting innovative instructional strategies that address not only the cognitive dimension but also foster affective and psychomotor engagement. Such an approach would lead to more meaningful and holistic learning, aligned with the demands of the professional world that emphasise critical thinking, collaboration, and mastery of practical skills. Furthermore, the results of this study may serve as a foundation for developing technology-integrated curricula in higher education, particularly in vocational and technical fields, to produce graduates who excel academically and are well-prepared to face the challenges of the digital era.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (468-479)
Online: http://journal.uny.ac.id/index.php/jitp

AI-based interactive digital game development in social studies learning to enhance students' computational thinking

Diana Noor Anggraini *, Kokom Komalasari, Pitria Sopianingsih, Nisrina Nurul Insani, Fajar Agustian Sudrajat
Universitas Pendidikan Indonesia, Indonesia.
***** Corresponding Author. E-mail: diana.anggraini@upi.edu

ARTICLE INFO

Article History
Received:
14 September 2025;
Revised:
24 November 2025;
Accepted:
3 December 2025;
Available online:
31 December 2025

Keywords
AI; Computational thinking; Interactive digital games; Social studies learning

ABSTRACT

Students' computational thinking skills in higher education remain relatively low, particularly in learning contexts that require problem decomposition, abstraction, and systematic problem solving. This condition highlights the need for innovative learning approaches that actively engage students through digital technology. This study aims to develop an Artificial Intelligence (AI)-based interactive digital game project in Social Studies learning to enhance students' computational thinking skills. The study employed a Research and Development (R&D) design involving a preliminary study, conceptual model development, validation, revision, and implementation. The research population consisted of undergraduate students enrolled in Social Studies Education courses at an Indonesian university, from whom 60 were selected using purposive sampling based on their participation in project-based learning activities. Data were collected through questionnaires, observations, and field notes. Qualitative data were analysed using interactive analysis techniques, while quantitative data were examined using Pearson correlation and simple linear regression. The findings reveal that student involvement in AI-based interactive digital game development projects positively influences computational thinking skills, including decomposition, pattern recognition, abstraction, and algorithmic thinking. These results indicate that integrating AI into project-based learning effectively supports the development of essential 21st-century skills.

How to cite:
Anggraini, D. N., Komalasari, K., Sopianingsih, P., Insani, N. N., Sudrajat, F. A., (2025). AI-based interactive digital game development in social studies learning to enhance students' computational thinking. *Jurnal Inovasi Teknologi Pendidikan, 12*(4), 468-479. https://doi.org/10.21831/jitp.v12i4.89738

INTRODUCTION

Computational thinking skills are among the key competencies students need to address learning challenges and complex problems in the digital age. However, computational thinking skills in Indonesia are still relatively low. Research shows that student learning outcomes are often below the Minimum Competency Criteria (KKM), especially in computational thinking (Rijal et al., 2021; Jamna et al., 2022). This is reinforced by PISA 2018 data, which shows that Indonesia ranks 73rd out of 78 countries with an average score of 379, far below the global average. The PISA assessment covers six levels of achievement, with levels 4, 5, and 6 measuring higher-level skills. At this level, the test assesses indicators of the ability to identify, reflect, formulate, interpret, evaluate, generalise, and utilise the information in the questions to solve complex problems

(OECD, 2019). These findings indicate that conventional learning approaches have not fully facilitated the optimal development of computational thinking.

The low level of computational thinking skills indicates that conventional learning approaches have not fully enabled students to develop logical and systematic thinking. Therefore, learning innovations are needed to encourage active student engagement and connect learning to real-world contexts through technology. In the digital age, technology has become an integral part of education by creating new learning patterns that are applied from kindergarten to college (Sudarmo et al., 2021; Sudarsana et al., 2019; Rachmawati et al., 2022; Wahyuningtyas et al., 2022). Technological developments, particularly Artificial Intelligence (AI), have opened up enormous opportunities in designing learning environments that are more interactive, adaptive, and student-centred (Sudarmo et al., 2021; Sudarsana et al., 2019). In this context, digital game-based learning has been widely recognised as a practical pedagogical approach for increasing student engagement, motivation, and higher-order thinking skills (Prensky, 2001; Spires, 2015). Several recent studies show that AI-based learning games can personalise the learning experience, provide real-time feedback, and assist students in the problem-solving process through adaptive mechanisms (Clark et al., 2016; Pujowati et al., 2024; Meiliawati et al., 2024).

Most research on AI-based game learning still positions students as users or consumers of learning media. Studies on gamification and digital literacy (Anwar et al., 2018; Mardina & Wacana, 2018) show positive effects on motivation and technological skills, but they have not explicitly examined the development of computational thinking as a structured cognitive process. Similarly, recent AI-based game research tends to focus on learning outcomes and student engagement, rather than on the process of how designing and developing AI-based games can train the main components of computational thinking, namely decomposition, pattern recognition, abstraction, and algorithm design (Lee et al., 2014; Fajri et al., 2019; Susanti & Taufik, 2021). This study aims to fill this gap by placing students in the role of creators through AI-based, interactive digital game development projects in social studies learning. Unlike previous studies that emphasise AI as an instructional tool, this study integrates AI into a project-based learning framework that requires students to identify problems, design game mechanisms, and systematically implement solutions using digital technology. The integration of project-based learning, the TPACK framework, and AI-based game development in this study contributes theoretically to the development of a learning model capable of fostering computational thinking through authentic, technology-based learning experiences.

The novelty of this research lies in the development of an interactive artificial intelligence-based digital game project specifically applied in social studies learning to improve students' computational thinking. This differs from the research by Anwar et al., (2020), which emphasises the use of digital media in learning in general, and Mardina et al., (2018), which focuses on digital literacy. This study introduces a novel approach to integrating AI technology into digital games while also placing students in an active-creator role. Thus, this study makes a new contribution by connecting social studies learning innovation with strengthening computational thinking as a key competency in the digital era. Based on the problem background, the general problem to be studied is how to develop an interactive digital game project using artificial intelligence in social studies learning to improve students' computational thinking.

METHOD

This study applies a Research and Development (R&D) design adapted from Borg & Gall (1989), a framework widely acknowledged in educational research for its systematic approach to developing and validating innovative products. The R&D approach employed in this study aligns with the four central characteristics outlined by Borg & Gall (1989), namely; 1) the conduct of preliminary studies to identify research findings relevant to the product being developed; 2) the development of a product informed by empirical findings; 3) the implementation of field testing in authentic contexts; and 4) the revision of the product based on identified weaknesses during field

trials. By following these principles, the study ensures that the model being developed is both research-grounded and responsive to practical demands.

The research was undertaken at the Indonesia University of Education, Bandung, Indonesia, over two years, demonstrating both continuity and depth of inquiry. The procedures were streamlined and adapted into four phases; 1) preliminary study, designed to identify the needs, opportunities, and constraints of integrating digital game-based learning in social studies; 2) conceptual model development, where a project design for AI-based interactive digital games was formulated in line with the TPACK framework; 3) validation and revision of the conceptual model, involving expert judgment and iterative refinement; and 4) implementation of the model in classroom practice to examine its effectiveness and feasibility.

The participants of this study were purposively selected, comprising a sample of 60 students from the larger student population of the Indonesia University of Education. The use of purposive sampling underscores the study's focus on recruiting participants directly relevant to the research objectives, particularly for assessing computational thinking skills within a social studies context. Data collection relied on three complementary instruments: questionnaires, observations, and field notes. The questionnaire item format used in developing this research instrument is the Likert summated rating scale measurement tool, which is an item writing format using a scale, where, with this writing format, respondents are asked to indicate their degree of agreement (conformity) and disagreement (nonconformity) with certain statements with five alternative answer choices. The questionnaire was then analysed using correlation/regression analysis (Sugiyono, 2021). Furthermore, the author hopes that this observation technique will enable him to collect data directly and obtain a clearer picture of the implementation of the AI-based Interactive Digital Game Development Project in lectures. Finally, field notes are a complementary tool for determining the effectiveness of interactive digital game development projects based on artificial intelligence in social studies learning to improve students' computational thinking. This triangulation of instruments enhances the credibility and richness of the data, as each instrument captures different dimensions of the research phenomenon: quantitative perceptions through questionnaires, behavioural dynamics through observations, and nuanced contextual details through field notes.

In terms of data analysis, both qualitative and quantitative approaches were employed to provide a comprehensive interpretation of the findings. Qualitative data were analyzed using the interactive model (Fraenkel & Wallen, 1993), which includes five key stages: 1) data reduction to focus on relevant information; 2) systematic categorisation and classification of data; 3) data display for more precise interpretation; 4) cross-site analysis to identify patterns and variations; and 5) drawing conclusions based on emergent insights. This iterative and reflective process strengthens the depth and trustworthiness of the analysis. On the other hand, quantitative data from the questionnaires were analysed using correlation and regression analyses (Creswell, 2018), enabling the study to statistically test relationships among variables, particularly the effects of the developed model on students' computational thinking.

Table 1. Instrument Designed

Variable	Indicator	Questions	Instrument Type
X: Interactive Digital Game Development Project	Interactive Digital Games Creation Project	11	Likert Scale
	Use of Digital Media Elements	5	
	Utilisation of Artificial Intelligence	4	
Y: Computational Thinking Skills	Decomposition	6	Survey of Study Habits and Attitudes
	Pattern Recognition	6	
	Abstraction	6	
	Algorithm	7	

Based on Table 1, there are two variables measured: X, the Interactive Digital Game Development Project and Y, the Computational Thinking Skills. In variable X, the measurement was carried out using a Likert-scale instrument with three indicators: Interactive Digital Games Creation Project (11 questions), Use of Digital Media Elements (5 questions), and Utilisation of Artificial Intelligence (4 questions). Meanwhile, variable Y was measured using the Survey of

Study Habits and Attitudes, with four indicators of computational thinking skills, namely Decomposition (6 questions), Pattern Recognition (6 items), Abstraction (6 items), and Algorithm (7 questions), as shown in Table 2.

Table 2. Validity Test

Variable	Items	Total Range	Sig.	Description
X: Interactive Digital Game Development Project	20	0.554 – 0.838	< 0,01	All Item Valid
Y: Computational Thinking Skills	25	0.482 – 0.793	< 0,01	All Item Valid

Validity testing was conducted by correlating the scores of each statement item (X1–X20) with the total variable. The score was obtained using Pearson Product-Moment correlation. There were 60 respondents in this study, so the table value of r at a significance level of 5% ($\alpha = 0.05$) with a degree of freedom (df) = 58 was 0.254. Based on the analysis results, all items from X1 to X20 have a calculated r value greater than the table r value (0.254) and a significance value (Sig. 2-tailed) of 0.000. The validity of the instrument on variable Y was tested using Pearson's Product-Moment correlation, which correlated the scores of each statement item (Y1–Y25) with the total variable score (TOTALY). There were 60 respondents in this study, so the table value of r at a significance level of 5% ($\alpha = 0.05$) was 0.254. Based on the results of the analysis in the Correlations table, it was found that all items of variable Y had correlation coefficients (calculated r) greater than the table r, with a significance value (Sig. 2-tailed) less than 0.05. The item–total correlation values ranged from 0.482 to 0.793, indicating a moderate to strong relationship between each item and the total variable score.

Table 3. Reliability Test

Variable	Cronbach's Alpha	N of Items
X: Interactive Digital Game Development Project	.946	20
Y: Computational Thinking Skills	.952	25

The results of the reliability test in Table 3, using Cronbach's Alpha, yielded a value of 0.946 with 20 items. This value is greater than 0.70, indicating that the research instrument has a very high level of reliability and is suitable for use as a measurement tool in research. The reliability test of the research instrument was conducted using Cronbach's Alpha to determine the internal consistency of the statement items on the Y variable. Based on the Reliability Statistics analysis, a Cronbach's Alpha of 0.952 was obtained with 25 statement items. The Cronbach's Alpha value exceeds the minimum required limit of 0.70, indicating that the research instrument has a very high level of reliability. This means that all statement items in variable Y exhibit good consistency and yield stable measurement results. Therefore, it can be concluded that the instrument for variable Y is highly reliable and suitable for further data analysis in this study.

Overall, the methodological rigour of this study lies in its combination of R&D design principles, purposive sampling, instrument triangulation, and mixed-method analysis. These elements collectively provide a robust foundation for developing, validating, and implementing an AI-based interactive digital game project in social studies learning, while also ensuring that the findings have both theoretical and practical significance.

RESULTS AND DISCUSSION

Results

Artificial Intelligence-Based Interactive Digital Game Development Project Model

This learning model emphasises a contextual approach, namely learning that directly links the material to everyday reality so that it has practical value and meaning for students, both as individuals, members of society, and citizens. The learning process design is structured in line with the characteristics of 21st-century learning, which demand critical thinking and problem-solving skills, creativity and innovation, as well as communication and collaboration. Within this

framework, project-based learning is considered relevant for building social meaning and 21st-century competencies.

Furthermore, this model integrates the TPACK (Technological Pedagogical Content Knowledge) framework as a basis for combining technological, content, and pedagogical strategies in the learning process. This integration is implemented in the Artificial Intelligence-Based Interactive Digital Game Development Project, whose syntax is shown in Figure 1. This project comprises five main stages: project idea and design development, material synchronisation, digital resource utilisation, and product assessment. In practice, these stages represent the concrete application of TPACK integration in project-based learning.

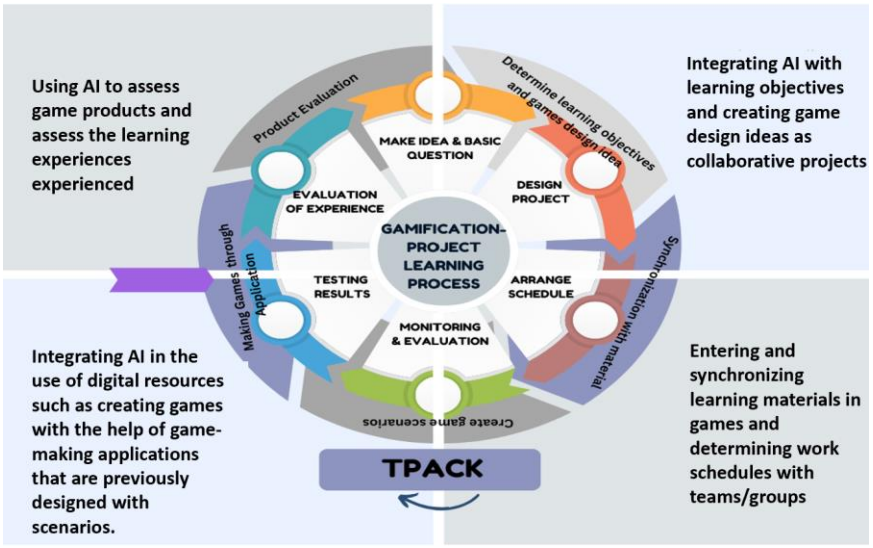

Figure 1. Syntax of the AI-Based Interactive Digital Game Development Project Model (Source: Author, 2025).

The project structure in Figure 1 for the development of this AI-based interactive digital game is based on the basic principles of project-based learning, which emphasise active engagement, collaboration, and the creation of tangible products. The first principle reflects the conventional stages of project learning, beginning with the formulation of ideas and essential questions that serve as the inquiry driver. The development of project designs follows this: the organisation of team schedules to ensure collaborative efficiency, the evaluation of project outcomes, and, finally, the reflective assessment of learning experiences. Such a structure ensures that learning is not only product-oriented but also process-oriented, thereby fostering both cognitive and metacognitive growth among students.

The second principle delineates the specific stages tailored for AI-based interactive digital game development. These include; a) defining the learning objectives and conceptualizing initial game ideas to ensure alignment with curricular outcomes; b) selecting and refining the central theme or core concept of the game; c) designing a game scenario that integrates pedagogical content with interactive digital elements; d) developing the digital game using appropriate applications and AI-driven tools; and e) evaluating the product through iterative testing and validation processes. This stepwise progression bridges theoretical learning objectives with practical technological implementation, enabling learners to construct knowledge actively through digital creativity.

The learning methods employed within this project are deliberately varied to accommodate different stages of the process and different learning styles. Traditional methods, such as lectures, provide conceptual grounding, while inquiry-based approaches stimulate critical questioning and exploration. Discussions and collaborative teamwork foster communication and collective problem-solving, whereas practical integration and simulations allow students to apply theoretical concepts in technology-assisted contexts. The inclusion of these methods demonstrates a blended learning approach that harmonises pedagogy and technology.

Central to this project is the integration of the TPACK (Technological Pedagogical Content Knowledge) framework, which operationalises the synergy between content, pedagogy, and technology. This integration is evident in several key dimensions; a) the utilization of AI tools to support the formulation of learning objectives and the co-creation of game design ideas, positioning game development as a collaborative learning project; b) the incorporation and synchronization of disciplinary learning materials into game structures, coupled with collaborative planning through team scheduling; c) the integration of ICT resources in game development using AI-based applications that guide scenario building and design implementation; and d) the employment of AI in evaluating both the game product and the learning experience, thereby ensuring a feedback-rich and reflective process—the process of digital game development into social studies learning, as seen in Figure 2.

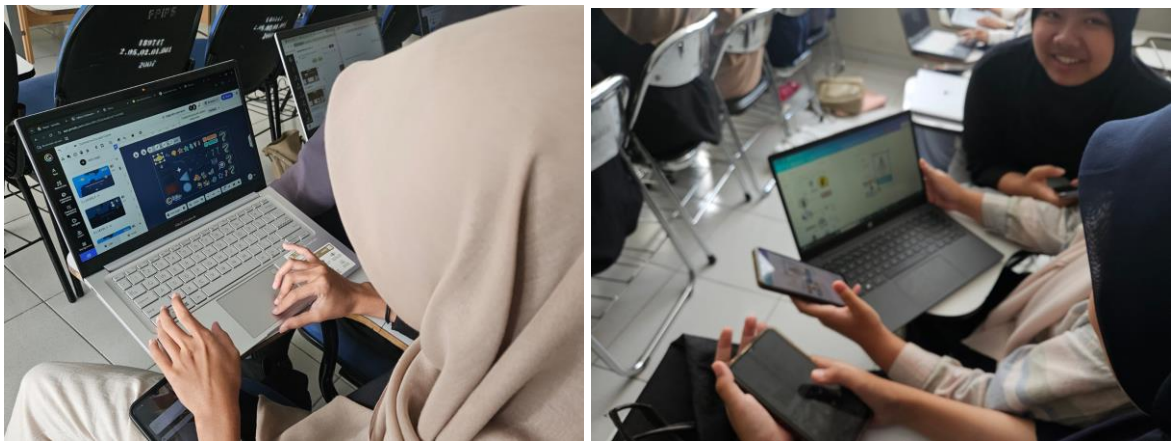

Figure 2. Processing Digital Game Development into Social Studies Learning

(Source: Author, 2025).

Taken together, these syntactic elements establish a comprehensive model for integrating AI-driven digital game development into social studies education. The approach not only equips students with essential 21st-century competencies such as critical thinking, creativity, collaboration, and digital literacy but also provides them with experiential learning opportunities that connect theoretical knowledge to practical applications in an authentic, technology-enhanced context.

Creating Interactive AI-Based Digital Games through Project Learning

The process of creating interactive AI-based digital games through a project learning approach consists of the following stages: 1) Students use project learning to come up with ideas for games to be created. The games are created by each individual using materials selected in advance during the inquiry stage; 2) Students identify the learning objectives to be included in the educational games; 3) Each student creates a storyboard for the game, which includes the scenarios to be depicted in the game; 4) Each student explores and uses game maker applications for each desired game criterion; 5) Lecturers monitor and supervise students' work from the beginning to the end of the product development process; 6) Each student presents their product and tests it in front of the class. Other students will respond to each other's products for the assessment process; 7) Lecturers assess students' products and conduct expert validation tests on the content and ease of use.

Figure 2 shows the results of students' work creating interactive games on economic growth in the trade sector, cities and communities, and social interaction, presented through adventure animations in Notebook Island, Halloween, and Froggy Jumps. The games are designed to be engaging, featuring adventure missions that involve solving puzzles to earn rewards in the form of sweets. Each puzzle contains questions about regional conditions in Indonesia. The games consist

of several puzzle levels, ranging from astronomical locations, time zone divisions in Indonesia, weather and climate, and geological conditions. Each question must be answered correctly to accumulate more points, as shown in Figure 3.

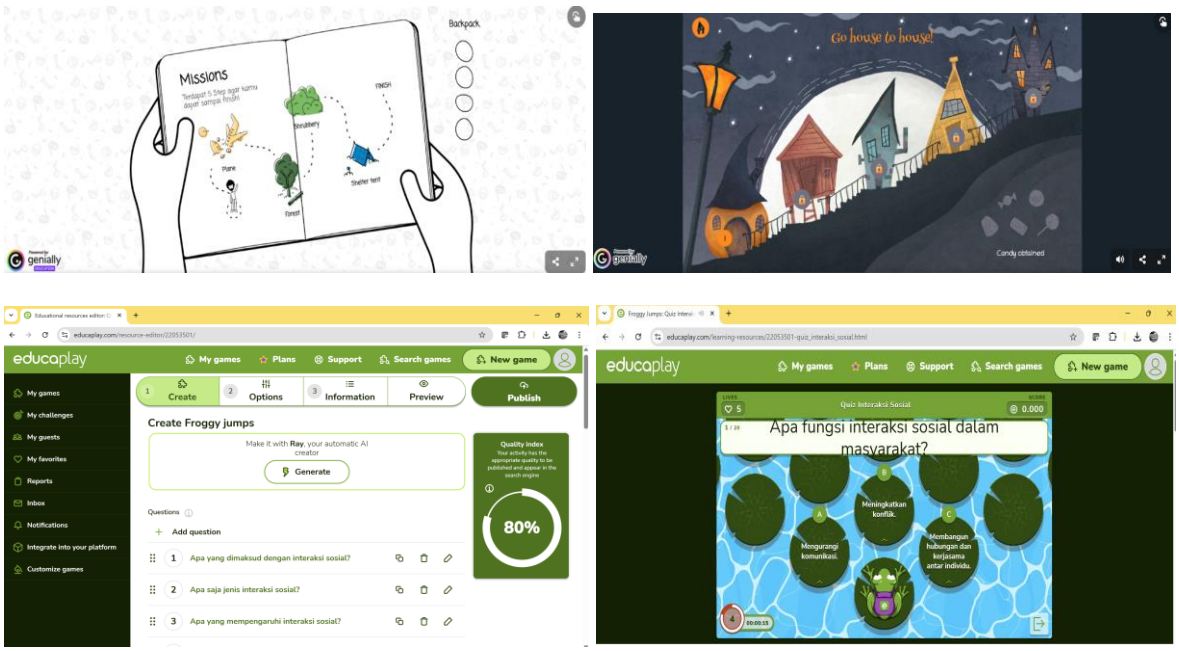

Figure 3. Genially and Educaplay Game Creation Products using AI

(Source: Author, 2025).

The Impact of AI-Based Interactive Digital Game Development Projects on Improving Students' Computational Thinking

The section on seeking influence in a programmed means evaluating the programme, namely the AI-Based Interactive Digital Game Development Project. This learning is carried out in ICT classes to achieve specific objectives that can increase students' computational thinking. Therefore, the concept of effectiveness is needed, which is included in the broader concept of evaluation. The implementation of ICT literacy learning through the AI-Based Interactive Digital Game Development Learning Project can be one of the efforts to support the success of improving students' computational thinking, with the following correlations.

Table 4. Correlation between Learning Projects for Creating Interactive Digital Games Based on AI and Computational Thinking

		(X)	(Y)
Learning Projects for Creating Interactive Digital Games Based on AI	Pearson Correlation	1	.548**
	Sig. (2-tailed)		.000
	N	62	62
Students` Computational Thinking	Pearson Correlation	.548**	1
	Sig. (2-tailed)	.000	
	N	60	60

**. Correlation is significant at the 0.01 level (2-tailed).

The results in Table 4 of the study indicate a significant positive correlation between the Artificial Intelligence (AI)-based Interactive Digital Game Development Project and an increase in students' computational thinking. Based on the correlation analysis, a Pearson correlation of 0.548 was obtained at the 0.001 significance level ($p < 0.01$), indicating a moderate correlation between the two variables. This finding indicates that the more actively students engage in the design,

development, and use of AI-based interactive digital games, the stronger their computational thinking skills will be. Based on the regression test results, the results are as described in Table 5.

Table 5. Regression Result

Model	R	R Square	Adjusted R Square
1	.548[a]	.300	.289
a. Predictors: (Constant), Learning Project			

The results of simple regression analysis show that the Artificial Intelligence (AI)-based Interactive Digital Game Development Project has a positive effect on improving students' computational thinking. Based on the regression model summary, an R value of 0.548 was obtained, indicating a positive relationship between the two variables. An R Square value of 0.300 indicates that the AI-based interactive digital game development project explains 30.0% of the variation in students' computational thinking abilities, with the remaining 70.0% influenced by factors outside this research model. Thus, these regression results reinforce the idea that AI-based interactive digital game development projects can be an effective learning strategy for improving students' computational thinking skills. Although its contribution is only 30.0%, the relationship's significant direction indicates that integrating AI into learning projects can be a key supporting factor in developing students' computational thinking competencies in the digital era.

Discussion

The results of the study indicate that the Interactive Digital Game Development Project, the Use of Digital Media Elements, and the Utilisation of Artificial Intelligence (AI) in social studies learning received a predominantly high response. In interactive digital game development projects, the majority of students stated that their involvement in creating digital media was constructive for understanding social studies material. Collaboration with lecturers, the use of digital platforms such as Genially, Canva, and Educaplay, and the availability of clear guidelines made students more focused on producing innovative learning products aligned with the curriculum. This shows that digital games are designed to be interactive, engaging, and educational, serving as a complement to modern learning media that help students learn basic concepts in a fun way (Faizatunisa & Kuniati, 2024). The integration of AI technology allows games to tailor learning materials and challenges to students' abilities, creating a more personalised and engaging experience (Pujowati et al., 2024). AI-supported games and simulations enable students to learn through hands-on practice and interaction with relevant content, making complex concepts easier to understand and apply (Meiliawati et al., 2024).

Regarding the use of digital media elements, student responses indicate that the AR-based interactive games and other digital media they created included features such as levels, reward systems, usage guides, and attractive, creative designs. The effectiveness of games is influenced by design, playing duration, additional instructions, and the integration of learning mechanics such as feedback and scaffolding (Clark et al, 2016). The application of digital games in learning creates an attractive system through elements such as points, ranks, levels, leaderboards, gifts, and so on (Rahardja et al., 2016). This shows that students do not focus solely on content delivery but also on engagement and user experience in the learning process. From the perspective of AI use, students reported significant benefits during the development of learning media. AI was used to customise content, provide recommendations for solutions to project challenges, and make the learning process more efficient, accurate, and structured. The presence of AI not only accelerated the development process but also encouraged students to think strategically in making decisions related to media design. Overall, the results of this analysis show that the AI-based Interactive Digital Games Creation Project contributes positively to improving the quality of project-based social studies learning. The integration of interactive digital games, creative digital media elements, and AI technology can create a collaborative, adaptive, and enjoyable learning environment aligned with students' needs in the digital era.

The results show that Computational Thinking Skills are in the high category, with respondents tending to rate the indicators at the "often" to "always" level. The four main aspects of CT, namely decomposition, pattern recognition, abstraction, and algorithm design, form the basis for analysis and problem solving (Fajri et al., 2019; Susanti & Taufik, 2021). In terms of decomposition, students demonstrated the ability to divide social studies material into smaller sub-topics, making it easier for them to translate it into interactive digital media. They can also identify specific social issues and organise them into simpler project stages to work on. In terms of pattern recognition, students are accustomed to linking their previous media creation experiences to be reused in new projects. They can recognise frequently occurring social studies concepts and compare various social issues to identify patterns of resolution that can be incorporated into games or interactive media. In terms of abstraction, students can select relevant information and filter out unnecessary data. They are also accustomed to simplifying complex social studies material to make it easier to understand, as well as focusing digital media content on the core issues. This ability demonstrates the ability to manage data and information critically to make learning media more effective.

In terms of algorithms, students can design systematic steps for developing digital learning media. They can sequence game flows, create coherent guides, and retest products to ensure they align with learning objectives. In addition, the ability to improve or rearrange stages demonstrates that students have the flexibility to address technical and conceptual obstacles. Overall, variable Y shows that students have good computational thinking skills. This is reflected in their ability to analyse, organise, and solve problems through interactive digital media. Thus, computational thinking is not only a technical skill but also a cognitive strategy that supports the success of project-based learning, especially in the context of developing AI-based interactive digital games. Additionally, CT enhances professionalism and problem-solving sensitivity and encourages innovation in creating more practical and efficient systems. The characteristics of CT include conceptual thinking skills, problem representation through abstraction, automated algorithm design, and a human-centred approach that combines technology with creative thinking skills (Simanjuntak et al., 2023; Aditya, 2018; Anggriani, 2023).

The results of the study indicate a significant positive relationship between the variable Artificial Intelligence-based Interactive Digital Game Development Project and the variable students' computational thinking, with a correlation coefficient of 0.407 and a significance level of 0.001. This shows that the more intensively students are involved in interactive digital game development projects that utilise digital media and AI, the higher their computational thinking skills. The results of simple regression analysis show that the Artificial Intelligence (AI)-based Interactive Digital Game Development Project has a positive effect on improving students' computational thinking. Based on the regression model summary, an R value of 0.548 was obtained, indicating a positive relationship between the two variables. The R Square value of 0.300 indicates that the AI-based interactive digital game development project explains 30.0% of the variation in students' computational thinking abilities, with the remaining 70.0% influenced by factors not included in this research model.

The results of the regression analysis showed an R^2 of 0.30, indicating that 30% of the variation in students' computational thinking skills can be explained by involvement in an interactive digital game development project based on Artificial Intelligence (AI). In the context of educational research, this value is categorised as a moderate effect size. A moderate effect size is important because educational phenomena are generally influenced by many complex variables, including cognitive, affective, social, and environmental factors. An effect size of 0.30 indicates that the AI-assisted project-based learning intervention made a practically meaningful contribution, although not a dominant one. This aligns with the characteristics of educational research, where a single learning model rarely explains the majority of the variance in learning outcomes. Other factors, such as learning motivation, students' digital readiness, initial computational thinking skills, the role of the lecturer, and the learning environment, also influence learning outcomes and explain the remaining 70% of the variance not accounted for in the model. The results of regression and correlation tests indicate that the relationship between AI-based digital game development projects and computational thinking skills is statistically significant. This significance indicates that

the relationship observed did not occur by chance, but rather reflects the real influence of the learning model on students' computational thinking skills.

This moderate effect size also highlights the study's limitations. First, the relatively small R^2 value indicates that the AI-based learning model is not yet capable of capturing the full complexity of students' learning processes. Computational thinking is a high-level skill that develops through iterative processes, long-term experience, and interactions with various learning contexts. It therefore cannot be fully explained by a single learning approach. Second, limitations are also related to the relatively limited number and characteristics of the sample. Third, the implementation of AI technology in learning is highly dependent on digital literacy, resource availability, and the readiness of both lecturers and students. Variations in technology-use skills can influence the effectiveness of learning models and contribute to unexplained variations in outcomes in this study. Overall, the moderate effect size ($R^2 = 0.30$) and strong significance indicate that the AI-based interactive digital game development project is an effective but complementary learning intervention, not the sole determinant of learning success. These findings confirm that integrating AI into project-based learning has significant potential to enhance computational thinking skills. However, it needs to be combined with other pedagogical strategies and further explored through follow-up research with more robust designs and a broader range of variables.

CONCLUSION

Based on the findings, the Artificial Intelligence-based interactive digital game development project in social studies learning contributed positively and significantly to increasing students' computational thinking abilities. Student involvement as creators in the process of designing, developing, and evaluating learning games has been proven to train key aspects of computational thinking, including decomposition, pattern recognition, abstraction, and algorithm design. These findings confirm that integrating AI into project-based learning not only produces innovative learning products but also strengthens higher-order thinking skills relevant to the demands of the 21st century. However, the results of this study need to be understood in light of several limitations. First, the coefficient of determination indicates that the learning model developed explains only part of the variation in students' computational thinking abilities. In contrast, the remaining variation is influenced by factors not examined in this study. Second, the relatively small sample size and the use of purposive sampling techniques limit the generalizability of the findings to other institutional or disciplinary contexts. Third, the measurement of computational thinking skills, which is partly based on perception instruments, may introduce subjective biases and does not fully reflect students' actual long-term performance. Given these limitations, future research should develop a more comprehensive research design, such as involving a larger and more diverse sample, using a longitudinal approach to observe long-term impacts, and combining performance-based assessment instruments to measure computational thinking more objectively.

ACKNOWLEDGMENT

The author would like to express his gratitude to the Universitas Pendidikan Indonesia for its academic support, facilities, and a conducive scientific environment, which enabled this research to be successfully conducted. He also expresses his highest appreciation to the Ministry of Higher Education, Science, and Technology (Kemendiktisaintek) for organising the PDDI Doctoral Scholarship Program.

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Jurnal Inovasi Teknologi Pendidikan
Volume 12, No. 4, December 2025 (480-491)
Online: http://journal.uny.ac.id/index.php/jitp

Development of an interactive digital flipbook for dissertation research dissemination

Marwajih[1], Anik Ghufron[1] *, Siswantoyo[1], Christina Ismaniati[1], Syahri Ramadhan[1], Wong Yoke Seng[2]
[1] Universitas Negeri Yogyakarta, Indonesia.
[2] Universiti Pendidikan Sultan Idris, Malaysia.
***** Corresponding Author. E-mail: anikghufron@uny.ac.id

ARTICLE INFO

Article History
Received:
25 September 2025;
Revised:
22 November 2025;
Accepted:
12 December 2025;
Available online:
31 December 2025.

Keywords
Academic transformation;
Digital flipbook;
Digital literacy;
Dissertation dissemination;
Research mapping

ABSTRACT

Doctoral dissertation outputs are often presented in static formats that limit accessibility, thematic exploration, and efficient information retrieval. At the Graduate School of Universitas Negeri Yogyakarta, dissertation mapping (2010–2025) has been disseminated through conventional reports lacking interactivity, thematic search features, and user-friendly navigation, making it difficult for users to explore research trends, methodologies, and findings. To address this limitation, a digital flipbook was developed to provide structured, accessible, and visually engaging access to dissertation data. This study employed a Research and Development (R&D) approach based on the Borg and Gall model, including needs analysis, design planning, prototype development, testing, revisions, large-scale trials, and expert validation. Participants in the needs analysis stage included lecturers and academic staff, while the product evaluation involved doctoral students as primary users. Data were collected through document analysis, interviews, and Likert-scale questionnaires, and analysed using descriptive qualitative and quantitative methods. The large-scale trial with 70 doctoral students yielded a mean score of 4.57 (very feasible) and high reliability (Cronbach's Alpha = 0.91). Pearson correlation showed a strong relationship between ease of navigation and visual appeal ($r = 0.72$, $p < 0.01$), while expert validation indicated high validity (Aiken's $V = 0.88$). The findings suggest that the dissertation flipbook is an effective digital dissemination tool that enhances research accessibility, supports thematic exploration, and strengthens research mapping. The flipbook contributes to institutional digital transformation, promotes open access, and supports a data-driven academic culture at the Graduate School of Universitas Negeri Yogyakarta.

How to cite:
Marwajih et. al., (2026). Development of an interactive digital flipbook for dissertation research dissemination. *Jurnal Inovasi Teknologi Pendidikan, 12*(4), 480-491.
https://doi.org/10.21831/jitp.v12i4.95817

INTRODUCTION

In the context of open science which emphasizes transparency, accessibility, and openness in sharing research findings, data, and methodologies higher education institutions are increasingly encouraged to ensure that research outcomes are not only produced but also widely accessible, reusable, and capable of generating greater scientific and social impact (Umbach, 202; Bertram et

al., 2023; Ross-Hellauer et al., 2024).. Open access to doctoral research enhances transparency, fosters academic collaboration, and supports knowledge transfer across disciplines (Organisation for Economic Co-operation and Development, 2010; Santos-Hermosa, 2023). Nevertheless, many institutional repositories still present dissertation information in static, text-based formats with limited interactive features and navigation, which can reduce accessibility and user engagement (Macgregor, 2019; Santos-Hermosa, 2023). Without thematic organisation, visual support, and interactive navigation, valuable research outputs may remain underutilised by students, lecturers, and policy makers (Nadkarni & Prügl, 2021). As a result, innovative dissemination formats are required to bridge the gap between research production and knowledge utilisation.

From a pedagogical and cognitive perspective, multimedia learning theory emphasises that information is more effectively processed when presented through well-designed combinations of text, visuals, and interactive elements (Clark & Mayer, 2016; Singh & Mayer, 2014). Digital flipbooks align with these principles by offering structured layouts, visual cues, and user-controlled navigation, thereby reducing cognitive load and enhancing comprehension (Hadiapurwa et al., 2021). When applied to dissertation dissemination, such features help users quickly grasp research scopes, methodologies, and key findings without reading full-length documents. This approach supports efficient research mapping and strengthens academic literacy among doctoral students and early-career researchers.

At the institutional level, systematic research mapping plays a crucial role in identifying academic strengths, emerging trends, and research gaps. A structured overview of dissertation topics enables universities to align doctoral research with strategic priorities, curriculum development, and societal needs (Schalkwyk et al., 2020). For the Graduate School of Universitas Negeri Yogyakarta, doctoral research has served as a central pillar in advancing scientific knowledge across multiple disciplines. Based on the institutional mapping of doctoral dissertations conducted between 2010 and 2023, various research trends, thematic patterns, and methodological orientations have been identified. However, the results of this mapping have primarily been presented in conventional formats such as printed reports or static digital documents, which lack interactivity, flexibility, and efficient search functionality.

As digital technology continues to reshape academic communication, the presentation of institutional research outputs must evolve accordingly. Traditional reports, while comprehensive, are often less engaging and less accessible to diverse user groups (Hew, 2016). Students, lecturers, and academic administrators require platforms that allow them to explore research themes dynamically, compare methodologies, and identify emerging areas of inquiry with ease. Digital flipbooks offer an innovative solution by integrating text, images, audio, and video into a single interactive environment. In educational contexts, flipbooks have been shown to increase learning engagement, improve visual comprehension, and enhance overall user experience (Abror et al., 2019; Deivam, 2023; Lubis et al., 2023; Purnomo et al., 2024).

Beyond improving engagement, flipbook-based media also support the development of digital skills and creative thinking. Erawati et al., (2024) reported that flipbook-based e-modules promote student creativity in technology-oriented courses, while Hadiapurwa et al., (2021) found that digital flipbooks enhance visual literacy among elementary students. The flexibility of flipbook platforms allows for multimedia integration, adaptive layouts, and mobile accessibility, making them suitable for diverse learning and information-seeking contexts (Lestari & Nur, 2023; Perdana et al., 2021). However, challenges such as usability issues, technical limitations, and digital literacy gaps must also be considered to ensure effective implementation (Listyawati & Muhyadi, 2017; Usman et al., 2024).

At the Graduate School of Universitas Negeri Yogyakarta, the absence of an interactive platform that systematically presents dissertation mapping results has limited the accessibility and practical utilisation of doctoral research. Valuable findings that could inform curriculum development, research supervision, and institutional policy are often confined to static documents that are not easily searchable or visually navigable. This condition reduces the potential impact of doctoral research as a strategic academic resource. Therefore, there is a pressing need to develop a

digital dissemination platform that not only organises dissertation data systematically but also facilitates multimedia-based exploration and thematic navigation.

This study adopts a Research and Development approach to design, develop, and evaluate a digital dissertation flipbook for the Graduate School of Universitas Negeri Yogyakarta. The flipbook integrates structured metadata, thematic categorisation, and interactive features to support efficient exploration of research topics, methodologies, and trends. A feasibility study is conducted to assess the product's effectiveness, usability, and visual appeal. By transforming static dissertation reports into an interactive digital flipbook, the flipbook aims to enhance research accessibility, promote knowledge sharing, and support academic decision-making.

From an institutional policy perspective, the development of this flipbook aligns with Universitas Negeri Yogyakarta's Strategic Plan (RENSTRA), which emphasises improving research quality and integrating digital technologies into academic services. As part of broader higher education digitalisation efforts, the flipbook also contributes to the Sustainable Development Goals (SDGs), particularly in promoting quality education through improved access to academic information.

Moreover, recent studies have highlighted that many institutional repositories still rely on static text-based files with limited discoverability and user engagement (Macgregor, 2019). Scholars advocate for the use of interactive interfaces, visual knowledge mapping, and thematic navigation to enhance the visibility and impact of academic outputs (Santos-Hermosa, 2023). By combining multimedia learning principles with open science practices, the dissertation flipbook serves as a bridge between traditional repositories and the modern demand for user-friendly knowledge navigation, an essential feature of 21st-century knowledge ecosystems.

In summary, this study does not merely digitise existing dissertation mapping reports but transforms how doctoral research is accessed, understood, and utilised at the Graduate School of Universitas Negeri Yogyakarta. The proposed flipbook represents an innovative academic infrastructure that supports transparency, accessibility, and optimal use of research outputs. It is expected to serve not only as a reference tool for doctoral students but also as a strategic resource for academic planning, research supervision, and institutional development. Therefore, the main aim of this study is to develop and evaluate an interactive digital flipbook as a digital dissemination platform for doctoral dissertation research. Furthermore, the model developed in this study has the potential to be replicated by other higher education institutions as part of their digital transformation initiatives in academic knowledge dissemination.

METHOD

This study employed a Research and Development (R&D) design to develop an interactive digital flipbook for disseminating doctoral dissertation research at the Graduate School of Universitas Negeri Yogyakarta (SPs UNY). The development process followed the Borg & Gall (1983) model, which includes needs analysis, design planning, prototype development, testing, revision, and dissemination. The population consisted of all doctoral dissertations produced at SPs UNY between 2010 and 2025 across three doctoral programs: Educational Research and Evaluation, Vocational and Technical Education, and Educational Science. A total sampling technique was applied, meaning that all available dissertations were included to ensure comprehensive research mapping.

Table 1. Research Instruments

No.	Instrument	Purpose	Main Content
1	Dissertation categorisation guide	Classify dissertation content	Themes, methods, findings, year, study program
2	Interview guide	Identify user needs and preferences	Open-ended questions
3	Evaluation questionnaire	Assess flipbook quality	Likert-scale items on usability and appeal

Secondary data were obtained from dissertation documents, which were coded and categorised according to research themes, sub-themes, methodologies, and key findings. Primary

data were collected through interviews and Likert-scale questionnaires involving doctoral students, lecturers, and academic staff to explore user needs and evaluate the flipbook's usability, readability, navigation, and visual appeal. The research instruments included (1) a dissertation categorisation guide, (2) an interview guide, and (3) a product evaluation questionnaire.

Data collection was conducted through document analysis, thematic coding, interviews, and user trials of the flipbook prototype. Qualitative data obtained from document analysis and interviews were analysed using the Miles & Huberman (1992) analytical framework, which includes data reduction, data display, and conclusion drawing. Meanwhile, quantitative data from Likert-scale questionnaires were analysed using descriptive statistics, including mean scores and standard deviations, to assess the product's feasibility and usability. Quantitative data analysis was conducted using SPSS software. In addition, instrument reliability was assessed using Cronbach's Alpha, and Pearson's correlation analysis was conducted using the framework. At the same time, quantitative data were analysed regarding the flipbook's visual appeal. The combination of qualitative and quantitative analyses enabled a comprehensive evaluation of the flipbook's feasibility, usability, and effectiveness as a research dissemination medium.

RESULTS AND DISCUSSION

Results

Preliminary Study and Needs Analysis

The preliminary stage focused on identifying user needs for disseminating doctoral dissertation research at the Graduate School of Universitas Negeri Yogyakarta. A document review of doctoral dissertations completed between 2010 and 2025, involving approximately 630 dissertations from three doctoral programs (Educational Sciences, Educational Research and Evaluation, and Vocational and Technology Education), was conducted to examine the distribution of research topics, dominant methodological approaches, and emerging research trends. This document analysis was complemented by semi-structured interviews with leaders of the Graduate School of Universitas Negeri Yogyakarta, doctoral supervisors, and academic staff to capture institutional demands for dissertation data to support academic development, research planning, and evidence-based policy formulation.

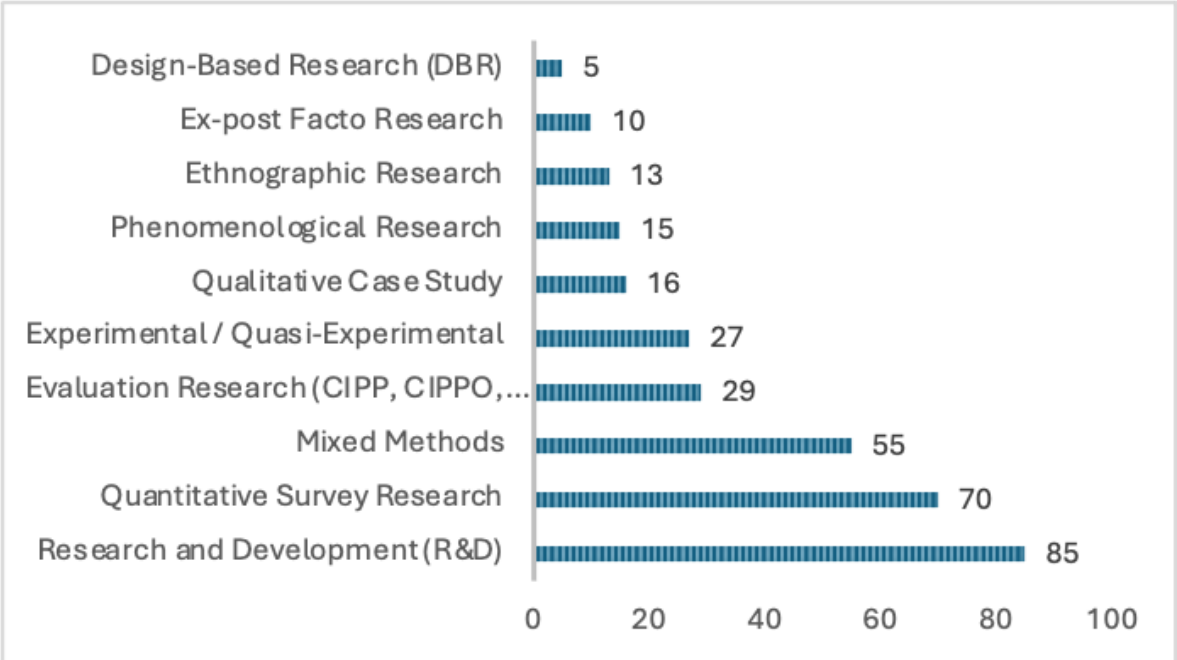

Figure 1. Top 10 Trends in Research Methods Used in Doctoral Dissertations (2010–2025)

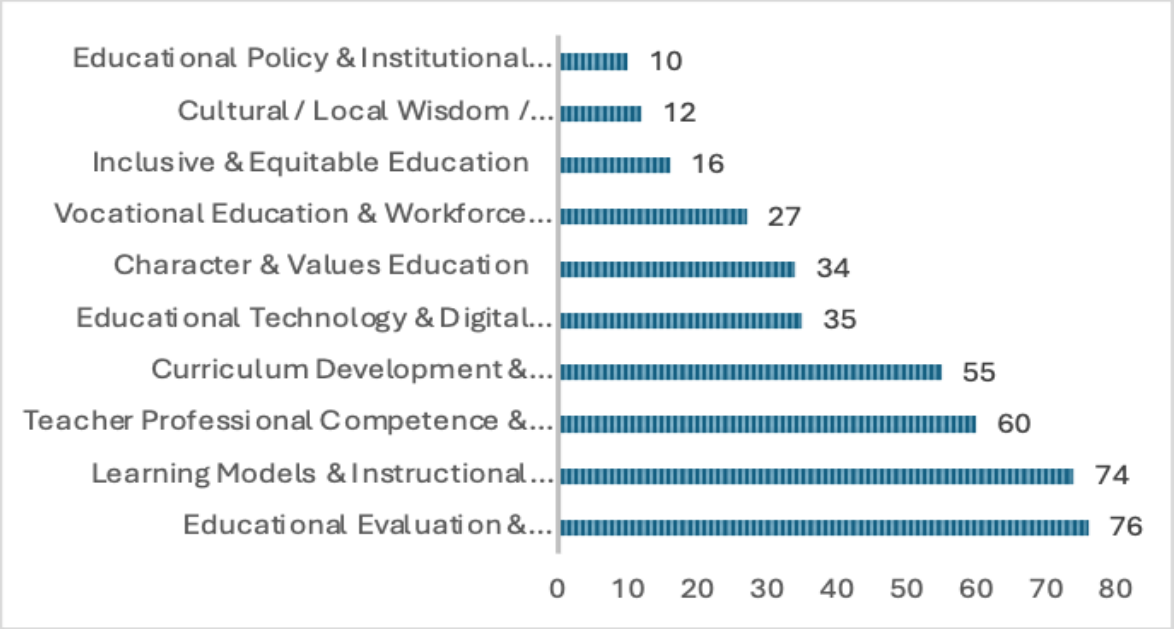

Figure 2. Top Ten Research Topic Trends in Doctoral Dissertations (2010–2025)

In addition, initial feedback was collected from doctoral students regarding their difficulties in locating previous dissertation studies. Students reported that searches for research topics, methods, and keywords were still largely conducted manually and scattered across separate documents, resulting in inefficient information retrieval. Overall, the preliminary findings indicated that dissertation information was fragmented and had not yet been integrated into a structured and interactive digital channel. This condition justified the development of an interactive digital flipbook as a research dissemination repository that presents dissertation mapping results in a systematic, visual, and accessible manner for diverse stakeholders.

Product Design and Prototype Development

Following the needs analysis, the flipbook was designed conceptually and technically to provide systematic, visual initial access to dissertation mapping results. On the opening page, the content is presented as visual representations of dissertation covers arranged to resemble a digital bookshelf, creating a sense of curation, order, and ease of orientation for users. Each cover represents a specific disciplinary cluster and functions as an entry point to more detailed dissertation information. This approach enables users to conduct intuitive preliminary exploration before engaging with structured metadata and academic content in greater depth.

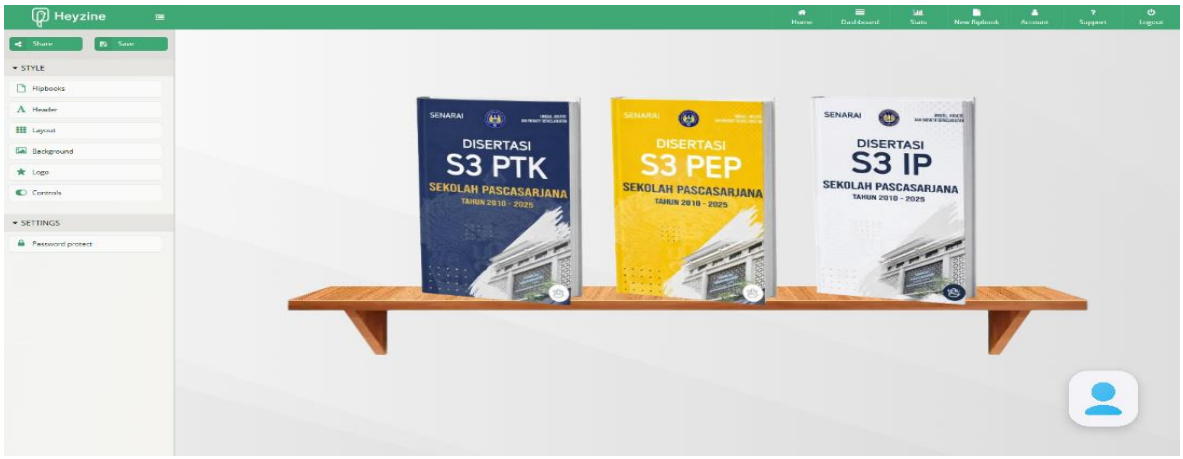

Figure 3. Digital Bookshelf Interface of the Heyzine-Based Interactive Flipbook for Dissertation Research Dissemination

Subsequent pages provide structured tabular visualisations that display detailed dissertation metadata, including research titles, years of completion, research methods, models or approaches, and thematic classifications. These tabular views enable users to examine patterns and trends across time, compare methodological preferences, and trace the development of specific research themes. The page-flip interaction, navigation controls, zoom, and search features embedded in the Heyzine interface further enhance readability and usability, supporting efficient exploration of large-scale dissertation datasets.

Importantly, the flipbook is designed not as a standalone repository, but as a complementary dissemination layer that can be integrated with the institutional digital repository of Universitas Negeri Yogyakarta. The dissertation data presented in the flipbook can be directly linked and synchronised with the official UNY e-repository (https://eprints.uny.ac.id/), enabling users to seamlessly transition from summarised and visualised dissertation mappings to full-text documents. This integration strengthens accessibility, ensures data consistency, and positions the flipbook as an interactive gateway that bridges high-level research mapping with authoritative archival sources.

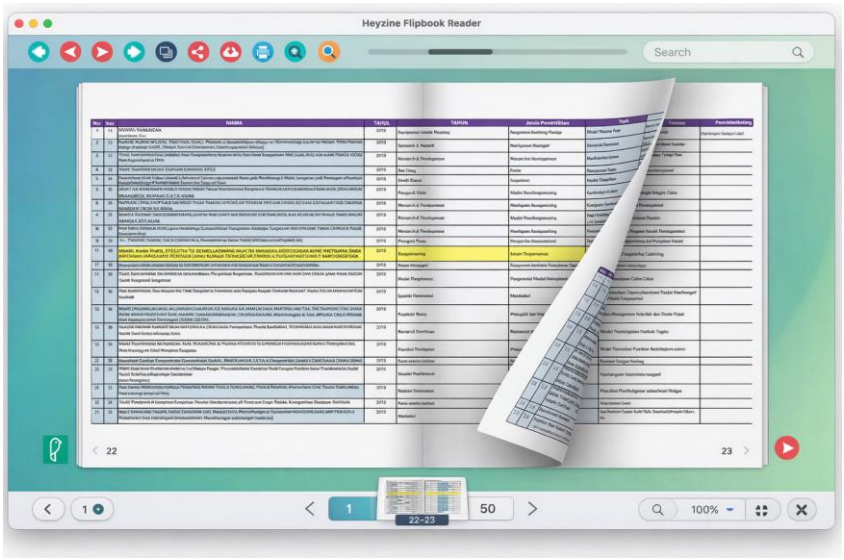

Figure 4. Tabular Visualisation of Doctoral Dissertation Metadata in the Heyzine Flipbook Interface

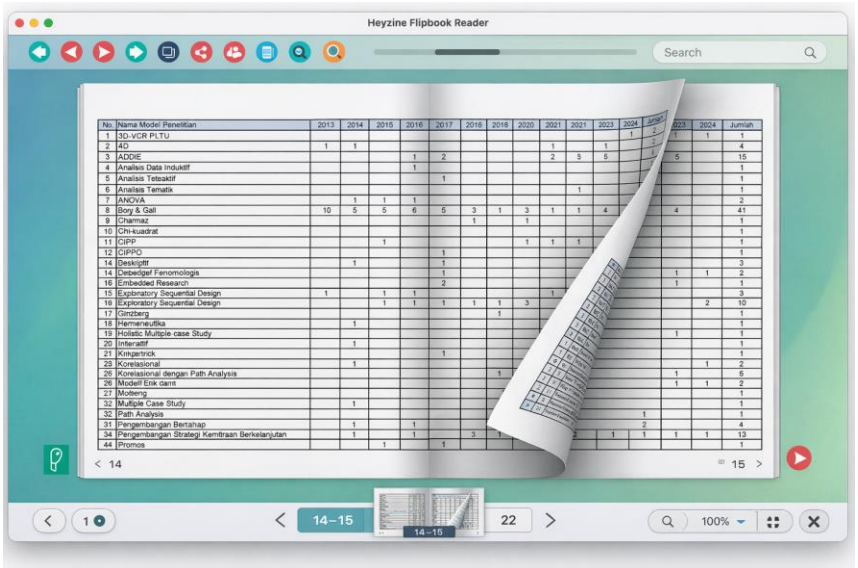

Figure 5. Research Method Distribution by Year

Internal Trial and Limited Trial Results

An internal trial was conducted to assess the prototype's initial feasibility before broader implementation. Ten doctoral students from different programs (Educational Research and Evaluation, Vocational and Technical Education, and Educational Science) tested the flipbook using their own devices. They explored its navigation, thematic search, and dissertation summaries. Using a 5-point Likert scale, the internal trial yielded an overall mean score of 4.40 (very feasible). The highest ratings were obtained for user benefits (M = 4.60) and visual appeal (M = 4.50), while ease of navigation received the lowest score (M = 4.20) yet remained within the feasible range. Feedback suggested minor improvements, including adding methodological filters, optimising text size for mobile reading, and providing a user guide page.

A limited trial with 10 doctoral students produced consistent results, with an overall mean of 4.40 and low variability across aspects (SD ≈ 0.39–0.44). The highest aspect was user benefits (M = 4.60; SD = 0.33), while ease of navigation remained relatively lower (M = 4.20; SD = 0.44), indicating a need for refinement in menu structure and quick-access features.

Table 2. Results of the Internal Trial of the Dissertation Research Flipbook

No.	Assessed Aspects	Mean Score	Category
1	Content Feasibility	4.40	Very Feasible
2	Readability	4.30	Very Feasible
3	Navigation Ease	4.20	Feasible
4	Visual Attractiveness	4.50	Very Feasible
5	User Usefulness	4.60	Very Feasible
Overall Mean		**4.40**	**Very Feasible**

Based on the results of the internal and limited trials, the author concludes that the Heyzine-based interactive dissertation flipbook demonstrates a high level of feasibility and practical value as a digital research dissemination tool. The consistently high mean scores across both trial stages indicate that the flipbook effectively supports users in accessing, exploring, and understanding dissertation research outputs in a more structured and visual manner. While minor usability refinements are necessary, these do not undermine the overall functionality of the system. Instead, they highlight opportunities for iterative improvement in line with the research and development framework. Overall, the trial findings affirm that the flipbook is ready for broader implementation and further enhancement, and has strong potential to function as an integrative gateway connecting dissertation mapping, academic exploration, and institutional digital repositories.

Table 3. Results of the Limited Trial

No.	Assessed Aspects	Brief Indicators	Mean	SD	Category
1	Content Feasibility	Metadata completeness, content relevance	4.40	0.39	Very Feasible
2	Readability	Font size, text/table readability	4.30	0.41	Very Feasible
3	Navigation Ease	Menu, Next/Back/Home buttons, table of contents	4.20	0.44	Feasible
4	Visual Attractiveness	Color scheme, layout, design consistency	4.50	0.36	Very Feasible
5	User Usefulness	Supports searching by topic/method/year	4.60	0.33	Very Feasible
Overall Mean			**4.40**	**0.39**	**Very Feasible**

Revision Outcomes and Large-Scale Trial

Based on feedback from the limited trial, revisions focused on improving navigation clarity and reading comfort. Enhancements included a clearer menu structure and quicker access to program-level sections, increased text readability on mobile devices, and extended search filters, particularly by research methodology. A short user guide page was also added, and interface consistency was strengthened. After revisions, a large-scale trial involving 70 doctoral students demonstrated improved feasibility. The flipbook achieved an overall mean score of 4.57 (very feasible), with strong ratings across all aspects: content feasibility (M = 4.55), readability (M = 4.50), ease of navigation (M = 4.45), visual appeal (M = 4.60), and user benefits (M = 4.75). These

results indicate high acceptance and perceived usefulness of the flipbook as a digital research dissemination medium.

Reliability and Correlation Findings

The evaluation instrument demonstrated excellent internal consistency (Cronbach's Alpha = 0.91), indicating high reliability in measuring user perceptions of the flipbook. Pearson correlation analysis identified a strong positive association between ease of navigation and visual appeal ($r = 0.72$; $p < 0.01$). This suggests that improvements in interface usability and navigation clarity were closely linked to users' perceptions of the flipbook's attractiveness, reinforcing the importance of user-centred design for digital academic dissemination products.

Table 4. Results of the Reliability Test

	Cronbach's Alpha	**N of Items**
	0.910	20

Table 5. Correlation Test Results

	Ease of Navigation	**Visual Appeal**
Ease of Navigation	1	.720**
Visual Appeal	.720**	1

** Correlation is significant at the 0.01 level (2-tailed).

Expert Validation and Aiken's V Analysis

Expert validation was conducted after the large-scale trial to ensure the product met academic and technical standards. Content experts reviewed the completeness, accuracy, and relevance of the dissertation metadata and thematic organisation. In contrast, media experts evaluated the visual design, readability, navigation structure, and functionality of interactive features (thematic search, hyperlinks, and responsive display). In addition to qualitative expert feedback, the content validity of the evaluation instrument was examined using Aiken's V. Results showed that item-level coefficients ranged from 0.82 to 0.94, with an average value of 0.88, exceeding the commonly accepted minimum criterion ($V \geq 0.80$) and indicating strong agreement among experts regarding item relevance. Across assessment domains, the mean Aiken's V values were: content feasibility ($\bar{V} = 0.89$; range 0.84–0.94), visual quality ($\bar{V} = 0.87$; range 0.82–0.92), navigation and features ($\bar{V} = 0.88$; range 0.83–0.93), and user benefits ($\bar{V} = 0.90$; range 0.85–0.94). Overall, these findings support the instrument's validity and confirm that the flipbook product is suitable for institutional dissemination.

Table 6. Content Validity Results of the Instrument Using Aiken's V

No.	**Assessed Aspect**	**V Value Range**	**Mean V**	**Category**
1	Content Appropriateness	0.84 – 0.94	0.89	Highly Valid
2	Visual Quality	0.82 – 0.92	0.87	Highly Valid
3	Navigation and Features	0.83 – 0.93	0.88	Highly Valid
4	User Benefits	0.85 – 0.94	0.90	Highly Valid
Overall Average			**0.88**	**Highly Valid**

Discussion

The development of the Dissertation Research Flipbook at the Graduate School of Universitas Negeri Yogyakarta responds to the institutional need for a structured, accessible, and digitally based research dissemination medium. The preliminary study revealed that dissertation information was scattered across separate documents, lacking adequate thematic search functionality. This condition made it difficult for students, lecturers, and academic administrators to explore research themes, methodologies, and trends efficiently. Therefore, the digital flipbook was developed as a strategic solution to integrate dissertation data into a systematic and interactive platform.

The limited trial results indicated that the flipbook prototype met the initial feasibility criteria, achieving an average score of 4.40 (indicating highly feasible). The highest ratings were in the user benefits and visual appeal aspects, suggesting that the flipbook was not only informative but also visually engaging. User feedback, such as the need for additional methodological filters and text size adjustments, provided essential input for further revision and development. This confirms that the Research and Development approach was implemented systematically and was user-centred. Such an iterative development process aligns with media development models that emphasise phased testing and user-based revisions to ensure product relevance and effectiveness (Gall et al., 2003; Sugiyono, 2015).

Following revisions, the large-scale trial involving 70 doctoral students yielded an overall mean score of 4.57, indicating improved product quality. The instrument reliability coefficient (α = 0.91) demonstrated excellent internal consistency, confirming the credibility of the evaluation results. Furthermore, the strong positive correlation between navigation ease and visual attractiveness ($r = 0.72$; $p < 0.01$) highlights the importance of intuitive interface design in enhancing user experience. These findings support previous studies by Davis (1989) and Kim & Park (2019), which showed that usability and appealing interface design significantly influence user satisfaction and technology acceptance.

From the user perspective, the flipbook facilitated faster access to dissertation references, supported cross-program research exploration, and provided clearer insights into methodological trends at the Graduate School of Universitas Negeri Yogyakarta. The interactive digital format proved more attractive and efficient than conventional reports, aligning with higher education digital transformation policies that promote technology-enhanced academic services. Previous studies conducted by Setiawan et al., (2019) and Yusuf (2021) also confirm that interactive digital media can enhance information accessibility, search efficiency, and the quality of academic decision-making.

Expert validation further strengthened the findings from user trials. Content experts confirmed the accuracy and completeness of the dissertation metadata, while media experts emphasised the professional design, readability, and device-independent interactivity of the flipbook. The Aiken's V content validity index (mean = 0.88) indicated a high level of expert agreement regarding the relevance and clarity of the evaluation indicators. This result is consistent with studies emphasising the importance of expert validation and content validity testing in ensuring the quality of educational development products (Azwar, 2001; Retnawati, 2016).

Conceptually, the flipbook serves not only as a documentation medium but also as a research-mapping tool that supports topic selection, identification of research gaps, and methodological trend analysis. This function positions the flipbook as a strategic academic resource for strengthening doctoral research quality and data-driven academic culture. Prior studies have shown that systematic research mapping helps institutions design more structured and sustainable academic development strategies (Burhan & Arifin, 2020; Kurniawan et al., 2019).

In practice, the flipbook can be integrated into the academic information system of the Graduate School of Universitas Negeri Yogyakarta as a digital learning resource and research reference tool. It can also support institutional decision-making on curriculum development, disciplinary mapping, and the evaluation of research direction. Future enhancements may include analytical features, visualisations of research trends, and direct links to national and international publication repositories. These findings support the notion that strengthening digital academic information systems enhances university governance and institutional competitiveness (Turrohmah & Suryanto, 2023). Overall, the results demonstrate that the Dissertation Research Flipbook at the Graduate School of Universitas Negeri Yogyakarta is a feasible, valid, and reliable digital dissemination medium. The product meets academic standards, aligns with user needs, and supports the institution's digital transformation agenda.

CONCLUSION

This institutional research aimed to develop a Digital Dissertation Research Flipbook for the Graduate School of Universitas Negeri Yogyakarta as a structured, accessible, and interactive

dissemination medium. The preliminary study revealed that dissertation information was scattered across separate documents and lacked thematic search capabilities, making it difficult for users to explore research themes, methodologies, and trends efficiently. The flipbook was developed using a Research and Development approach, which included needs analysis, design planning, prototype development, limited trials, product revision, large-scale trials, and expert validation. The limited trial results showed that the flipbook demonstrated high feasibility, with an average score of 4.40. After revisions, the large-scale trial involving 70 doctoral students produced a higher mean score of 4.57, supported by excellent instrument reliability ($\alpha = 0.91$). These findings indicate that the flipbook demonstrates strong quality across content feasibility, readability, ease of navigation, visual appeal, and user benefits. Correlation analysis revealed a strong positive relationship between navigation ease and visual attractiveness ($r = 0.72$; $p < 0.01$), indicating that an intuitive interface significantly enhances user experience. Furthermore, expert validation supported by Aiken's V analysis (mean V = 0.88) confirmed that the flipbook meets content validity and media feasibility standards. Thus, the Digital Dissertation Research Flipbook of the Graduate School of Universitas Negeri Yogyakarta is considered suitable for institutional implementation. Overall, the flipbook serves not only as a documentation tool but also as a research-mapping platform, assisting students, lecturers, and academic administrators in understanding research trends, identifying research gaps, and supporting academic decision-making. The product aligns with user needs and supports the Graduate School of Universitas Negeri Yogyakarta's digital transformation agenda.

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