JURNAL INOVASI

Teknologi Pendidikan

Volume 13, No 1, March 2026

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JURNAL INOVASI Teknologi Pendidikan

Volume 13, No. 1, March 2026

Volume 13, No 1, March 2026

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

JURNAL INOVASI

TEKNOLOGI PENDIDIKAN

IPTPI APS-TPI

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

JURNAL INOVASI
Teknologi Pendidikan

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

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

Volume 13, No 1, March 2026

ISSN 2407-0963 (print)
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Volume 13, No. 1, March 2026 (1-13)
Online: http://journal.uny.ac.id/index.php/jitp

Development of interactive media based on Google Sites for independent learning of extracurricular computer-aided design and drafting students

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ARTICLE INFO

Article History
Received:
21 May 2025;
Revised:
17 August 2025;
Accepted:
18 August 2025;
Available online:
31 March 2026.

Keywords
Computer-aided design and drafting; Google Sites; Independent learning; Interactive media;

ABSTRACT

The implementation of Computer-Aided Design and Drafting (CADD) extracurricular training at Vocational High School Turen still relies on printed books and teacher demonstrations, which limit students' independence in learning and restrict the duration of practice. This development was carried out to help students learn independently, without time constraints, and to make it accessible from anywhere. This research is a development study using the ADDIE development model, which consists of five stages: 1.) Analyse; 2.) Design; 3.) Develop; 4.) Implement; 5.) Evaluate. The research and development process began with analysing student characteristics and needs, designing the concept, creating the product, validating it with subject matter experts and media experts, and testing the product using simple random sampling on three trial subjects participating in the CADD extracurricular activity at Vocational High School Turen, followed by evaluation based on improvement suggestions. The research instruments were based on media development theory, BNSP eligibility standards, and assessment standards set by the head of the standards, curriculum, and education assessment body. Based on expert media validation, the percentage was 88%, and expert material validation was 92%. The trial results yielded a 93% response rate from students regarding the developed product. The results of this research and development indicate that the interactive training media developed in Google Sites meet the criteria for suitability as training media. For future research, it is necessary to enhance the presentation and completeness of the material, as well as provide more complex exercises that keep pace with industry developments.

How to cite:
Efendi, G. F. A., Widiyanti & Tuwoso. (2026). Development of interactive media based on Google Sites for independent learning of extracurricular computer-aided design and drafting students. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 1-13. https://doi.org/10.21831/jitp.v13i1.85559

INTRODUCTION

The rapid development of Industry 4.0 is driving a positive transformation in the sustainability of technology-based learning, enabling students to learn, innovate, and utilise technology (Nugroho et al., 2024). Integrated implementation of digital technology enables interactive and efficient learning (Fitrianti et al., 2024). Vocational High Schools, as educational institutions at the vocational secondary level, have the responsibility to respond to current developments to realise interactive and efficient learning, thereby increasing the quality of graduates (Syarif & Janata, 2024). In this case, schools and teachers play a role in developing models, media, and learning resources to help students

keep up with current Industry 4.0 developments and become competent graduates (Nurtanto et al., 2020).

According to Alimuddin et al. (2023), the integration of technology enables students to learn flexibly, without being limited by space or time, as it can be accessed virtually. In addition, virtual learning allows students to access a broader range of learning resources, including learning videos, e-books, and other interactive digital learning platforms (Indarta et al., 2022). Utilising interactive digital learning media helps students learn. It enables teachers to enrich their teaching skills, thereby improving the efficiency and effectiveness of learning activities and enhancing the quality and productivity of learning (Tahir et al., 2024).

In addition to utilising technology to develop learning media, extracurricular activities are needed to develop students' character and skills to become competent (Azizah & Maknun, 2022). Extracurricular activities are effective in helping students develop and explore their talents and interests by extending learning beyond classroom hours (Salsabila et al., 2023; Yusriyah & Retnasari, 2023). Therefore, Vocational High School Turen established an extracurricular program in Computer-Aided Design and Drafting (CADD).

CADD Extracurricular at Vocational High School Turen demonstrates the school's commitment to forming students who are characterised by competence and ready to compete in competitions and the world of work. The routinely followed competitions are the Vocational High School Student Competency Competition (LKS SMK) in Mechanical Engineering, CAD, and Plastic Die Engineering. According to Ardianto et al., (2023), early preparation is key to success in the Student Competency competition, as it trains students through extracurricular activities facilitated by the school. In addition, these two fields of competition require advanced competence in operating Autodesk Inventor Professional, so the school's formation of this extracurricular activity is the right step. Through this application, students can create precise designs, perform simulations, and analyse designs before they are physically produced. To master this application, it is not enough to rely solely on classroom meetings (Akbar et al., 2024).

During implementation, the CADD extracurricular programme at Vocational High School Turen still uses printed modules and teachers' direct demonstrations. The use of printed modules and teacher-led demonstrations in extracurricular activities can lead students to become overly dependent on the provided material, hindering their independence in learning and limiting their study time. Therefore, it is necessary to use interactive learning media that are easily accessible to support student learning independence and student readiness to face the era of the Industrial Revolution 4.0 (Smaragdina et al., 2020). Supporting this statement, Fadilah & Dj (2023) found that the use of learning media in e-modules is more effective than that of printed teaching modules. In addition, printed teaching modules have limitations in displaying video, animation, and audio and require high printing costs, so e-modules are considered more effective because they are integrated with the internet, support interactive media, and increase student learning motivation (Ginting et al., 2024; Puspitasari, 2019). Therefore, it is necessary to develop an e-module in the form of an interactive media integrated through the Google Sites website. With the development of this integrated interactive media, it is hoped that it will support students' independence in learning and creativity with a positive attitude, thereby significantly improving the effectiveness of the learning process and student learning outcomes (Arifin et al., 2021; Ma, 2022).

The use of Google Sites as a supporting medium for interactive media development is based on the findings of Maharani et al., (2024), that Google Sites websites are one of the interactive media that contain various types of content in the form of videos, animations, audio, presentations, and so on, which can be shared according to user needs. Additionally, Google Sites is a free platform that is easy to access and integrates with Google Workspace, making it effective for developing interactive, collaborative, and adaptive educational media or training tailored to the needs of modern education (Islanda & Darmawan, 2023; Juwariyah et al., 2025).

This research and development of interactive media based on Google Sites aims to create an effective training media design as part of an effort to empower the CADD Extracurricular Programme at Vocational High School Turen, and to determine the product's feasibility based on practicality, interactivity, and efficiency. The materials are comprehensive, covering an introduction to Autodesk Inventor Professional 2024, website usage guidelines, 3D modelling, including 2D sketching,

standard 3D parts and sheet metal, standard assembly, welding, mould design, disassembly videos, Inventor Studio, 2D drawings, and practice questions. This media is practical because it is available on a website accessible anytime, anywhere, on any device, including smartphones, tablets, laptops, and computers. The interactive element of this media stems from the integrated content and the availability of a comment feature for users. The efficient aspect of this media development is due to the website's ease of integration and updating various materials, including files (PDF) and videos, as well as practice questions, all within one website. With the development of this media, it is hoped that it will assist extracurricular activities in providing practical and efficient training tools, thereby enhancing students' motivation and competencies in CAD, while also improving the quality of vocational high school graduates, particularly in the field of Mechanical Engineering, in facing competition in the era of the 4th Industrial Revolution.

METHOD

This study utilises research and development (R&D). The development aims to design interactive media in Google Sites for extracurricular activities. This research and development uses the ADDIE model because it is responsive and flexible, enabling it to accommodate any objectives set as its orientation (Branch, 2009). The ADDIE model also provides opportunities for evaluation at each stage of the development process, which positively impacts product quality by minimising error rates. Additionally, this model was chosen because it uses a systematic, sequential approach, enabling the effective and dynamic creation and development of training platforms while supporting the implementation of training (Fitriyah et al., 2021; Sugihartini & Yudiana, 2018). The ADDIE model development procedure is illustrated in Figure 1.

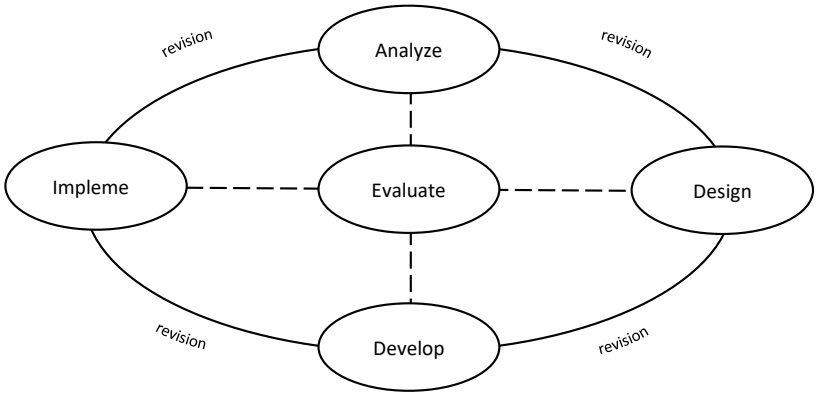

Figure 1. ADDIE Development Concept

Based on the concept Diagram above, the procedure for developing Google Sites-based e-modules is as follows.

1. The analysis stage serves to identify possible gaps during the implementation of extracurricular activities. Several gaps were identified, including the need to supervise teachers' busy schedules, limited learning resources for students, and a lack of student independence in their learning. This data was obtained through direct observation and brief interviews with the supervising teacher, leading to the conclusion that an integrated training medium is needed to present comprehensive materials, tutorial videos, and practice questions.
2. The design stage aims to create an initial concept that addresses the problems identified in the analysis and is reinforced by literature studies, resulting in a product development plan in the form of a website containing material in the form of module files (PDF), tutorial videos, and practice questions, the layout of which is designed in the form of a storyboard.
3. The development stage is the product development step based on the design stage, starting from website creation, material creation, tutorial video creation, and practice question creation. Website development integrates materials, video tutorials, and practice questions. The website

layout is based on the storyboard created in the design phase. After development is complete, media and content experts conduct validation, and the results are analysed.

4. The implementation phase is the testing phase of the product development process that has been validated by experts on test subjects, where the test subjects provide feedback through a questionnaire containing user assessment instruments, to allow users to express their opinions and suggestions.
5. The evaluation stage is used to assess product quality. Therefore, this evaluation stage is based on the results and suggestions from expert validation, as well as user responses after product testing. Product evaluation is conducted based on the assessments, critiques, and suggestions provided.

Validity Test

Validity testing was conducted using validation instruments, and the media and materials developed were validated with these instruments. The media and material validation instruments were given to lecturers from the Department of Mechanical and Industrial Engineering, Faculty of Engineering, State University of Malang, and CADD Extracurricular Supervisors from Turen Vocational School to act as validators. The validation results will be used to adjust the product development process.

Design of Product Trial

Product trials were divided into two stages. The first stage is by submitting a validation questionnaire to media experts with assessment aspects such as colouring, word selection and grammar, screen display, presentation, animation and sound, as well as notes and suggestions, and submitting a validation questionnaire to material experts with assessment aspects such as material feasibility, presentation feasibility, contextual feasibility and notes and suggestions. The second stage includes preparing questionnaires, distributing products, and distributing user assessment questionnaires to test subjects.

Test Subject

The test subjects were vocational school students in Turen who participated in the CADD extracurricular programme during the 2024/2025 academic year. The subjects were selected using simple random sampling, without regard to the abilities or strata of the extracurricular members (Fajar et al., 2021). The sample size for the product trial subjects was determined based on 10% of the large population or 20% of the small population (Long et al., 2025). With a total of 12 extracurricular participants, which constitutes a small population, the research sample consisted of 3 students selected at random.

Data Collection Instrument

This stage encompasses various methods, including interviews, questionnaires administered through the Media Expert Validation Instrument, Material Expert Validation Instrument, and User Assessment Instrument, as well as document acquisition to document the extracurricular process. Additionally, images are captured during observation and research activities. The development of instruments in this study was conducted systematically and based on theory to obtain valid and reliable data, in line with the research objectives. The interview guide was developed based on quality indicators for learning products derived from media development theory and National Professional Certification Agency standards to explore in depth users' perceptions and experiences with the developed products. The questionnaire was designed as a Likert scale with four levels of assessment, with each item developed based on indicators of material aspects, visual appearance, ease of use, and media interactivity. Meanwhile, a user assessment instrument, in the form of a product evaluation sheet, was used to evaluate the quality and suitability of the learning media against the assessment standards provided by the head of the standards agency, the curriculum, and educational assessment.

Data Analysis Technique

The data analysis technique uses two methods: descriptive qualitative analysis and descriptive quantitative analysis. Descriptive qualitative data are obtained through observations, interviews, and documentation from the distribution of validation and user questionnaires, which will strengthen the results of the quantitative data. Quantitative data is obtained through quantitative analysis of results from distributing validation questionnaires to media experts, material experts, and user assessment response questionnaires. The analysis was carried out using the formula referred to Pangestu et al., (2024), so that Formula 1 was obtained as follows.

$$P = \frac{\sum n}{\sum N} \times 100\% \quad (1)$$

The P is the percentage obtained by distributing the questionnaire, n is the number of values obtained, and N is the maximum number of values on the existing rating scale.

Evaluations conducted by media experts, material experts, and users yielded results as percentage assessments. The evaluation criteria for assessing product feasibility are determined using the following grouping in Table 4, as per Darnawati et al.. (2025).

Table 4. Percentage Determination Criteria

No.	Rating Scale	Interval	Category
1	4	81% < Skor < 100%	Very good
2	3	61% < Skor < 80%	Good
3	2	41% < Skor < 60%	Fairly good
4	1	21% < Skor < 40%	Not good

RESULTS AND DISCUSSION

Results

Analysis Result

The students were so engrossed in the teacher's explanation that the product to be developed was an interactive media-based Google Sites platform for the CADD extracurricular activity, comprising module files (PDF), tutorial videos, and practice questions, all integrated into a single website. The objectives of establishing this extracurricular activity are divided into three categories, each with expected competency outcomes, including: 1.) Technical skills, including the ability to operate software, understand the principles and standards of technical drawings in the industrial world, and create advanced technical designs; 2.) Soft skill development, including creativity and problem-solving through existing design projects; 3.) Career preparation through design portfolios, certification preparation, support for competition preparation, and facilitating industry-academia collaboration.

Based on the objectives of the extracurricular programme, some of the materials to be presented in product development to expand the participants' knowledge in manufacturing design include: 1. Tips and tricks for operating the Autodesk Inventor application; 2.) Creating 3D designs through the manufacturing process; 3.) Utilising all assembly features; 4.) Utilising presentation features and Inventor Studio.

Product Design and Storyboard Results

The results of the material formulation are divided into 13 topics, including: 1.) Introduction to Autodesk Inventor; 2.) Website usage guidelines: 3.) Tips and tricks for using Autodesk Inventor; 4.) Project features: 5.) 2D Sketching; 6.) 3D Partition Modelling; 7.) 3D Sheet Metal Modelling; 8.) Assembly Standards; 9.) Welding; 10.) Mould Design; 11). Inventor Studio; 12.) Video presentation on disassembly; 13.) 2D Drawing. The materials are organised according to the menus and features

available in Autodesk Inventor Professional 2024. Additionally, there are practice questions divided into several difficulty levels. All materials and practice questions will be integrated into a single Google Sites website link that includes several features to assist users, such as: 1.) Browser bar; 2.) Menu bar; 3.) Back button; 4.) Home button; and 5.) Next button. The website layout can be viewed through the storyboard in Figure 2 below.

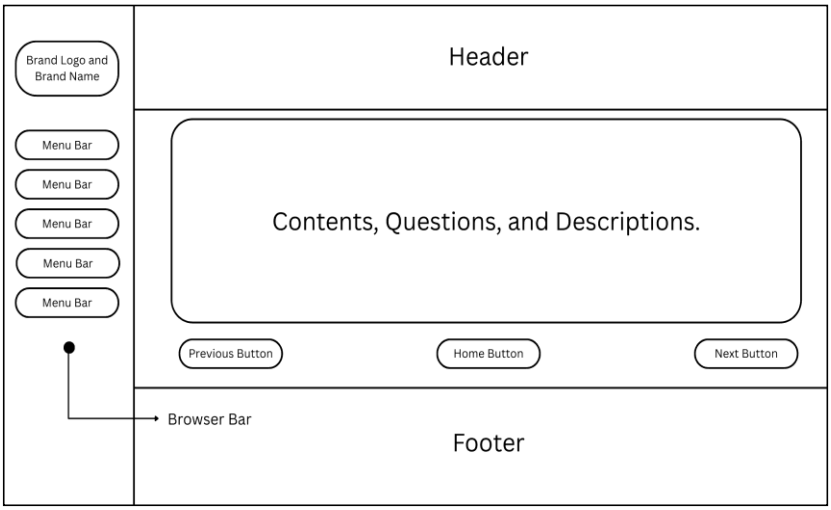

Figure 2. Website Storyboard

Results of Interactive Media Development Based on Google Sites

The results of developing interactive media in Google Sites for CADD Extracurricular are presented on a website that integrates all materials, including module files (in PDF format), tutorial videos, and practice questions. The materials, in the form of module files (PDF), consist of 13 modules, two tutorial videos, and two types of practice questions in the fields of Mechanical Engineering CAD and Plastic Die Engineering. Each question has three levels of difficulty: easy, medium, and difficult. The appearance of the interactive media development based on Google Sites is shown in Figure 3 below.

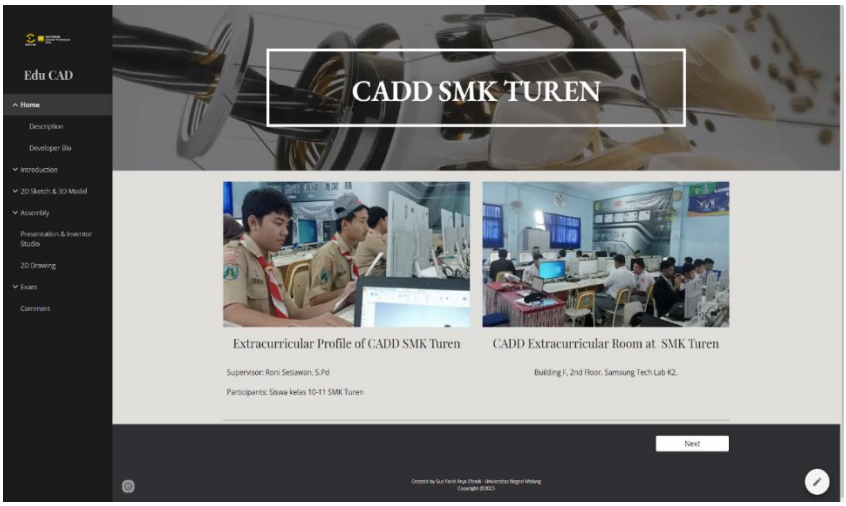

Figure 3. Initial View of the Google Sites Website on a Computer Screen

Like most websites, this development product can be accessed using any device, including laptops, computers, PCs, smartphones, and tablets. The e-module materials and practice questions, in the form of files (PDF) and video tutorials, are synchronised with Google Drive, allowing them to be accessed online by opening the website or downloaded to a device. There is also a task collection available in the media using the provided link. The steps for using the product are illustrated in Figure 4 below.

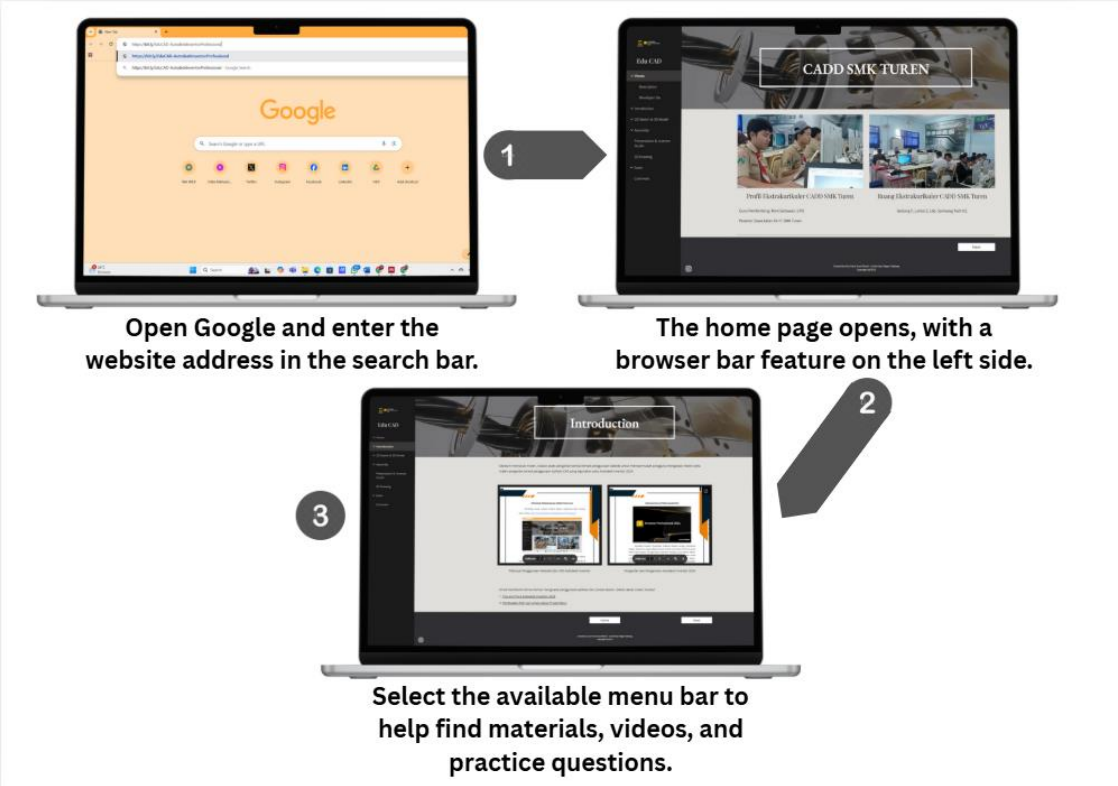

Figure 4. Product Usage Steps

Media Expert Validation Results

The results of the media expert validation are presented in the diagram in Figure 5 below.

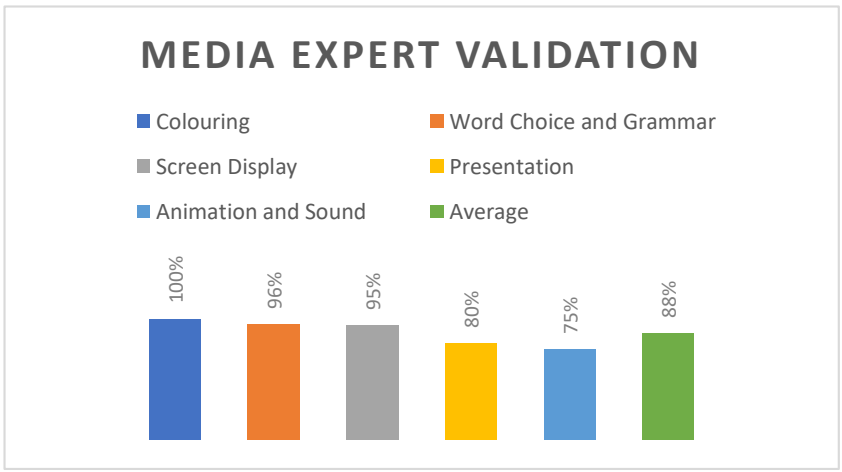

Figure 5. Media Expert Validation Results

The graph above shows the percentage of the five assessment aspects with 18 instrument items at 88%. The colouring aspect consists of 2 items with an average score of 4, the word choice and grammar aspect consists of 3 items with an average score of 3.8, the screen display aspect consists of 5 items with an average score of 3.8, the presentation aspect consists of 5 items with an average score of 3.2, and the animation and sound aspect consists of 3 items with an average score of 3. Based on the expert validation results, it was concluded that the interactive media developed using Google Sites for the CADD extracurricular activity is very good and therefore suitable for use and product testing. The suggestion was to add text to the tutorial videos and provide one for each material.

Material Expert Validation Results

The results of the material expert validation are presented in the diagram in Figure 6 below.

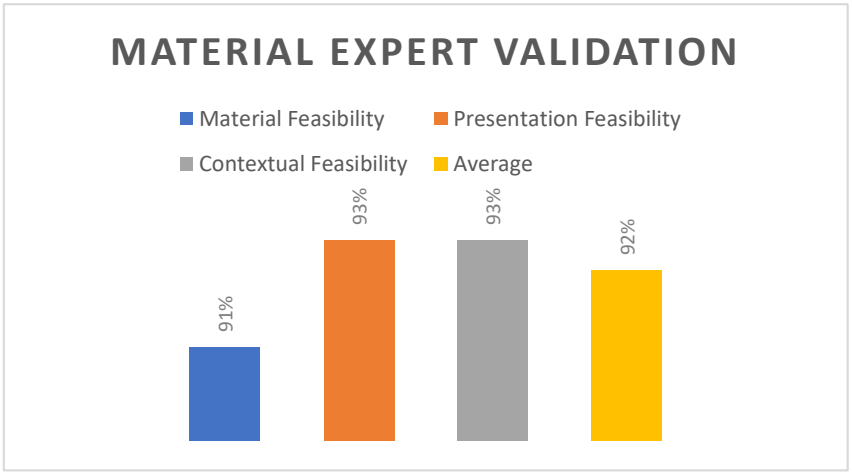

Figure 6. Material Expert Validation Results

The graph above shows the percentage of the three aspects with 14 instrument items at 92%. The material feasibility aspect consists of four items, with an average score of 3.6. The presentation feasibility aspect consists of five items, with an average score of 3.7. The contextual feasibility aspect comprises 5 items, with an average score of 3.7. Based on the expert validation results, it is concluded that the interactive media based on Google Sites for the CADD extracurricular activity is very good and therefore suitable for use and product testing. Additionally, it is recommended that the practice questions be aligned with the latest competition questions, specifically those from the past 1 to 2 years.

Results of Product Testing

Information on the results of product trials is presented in chart form in Figure 7 below.

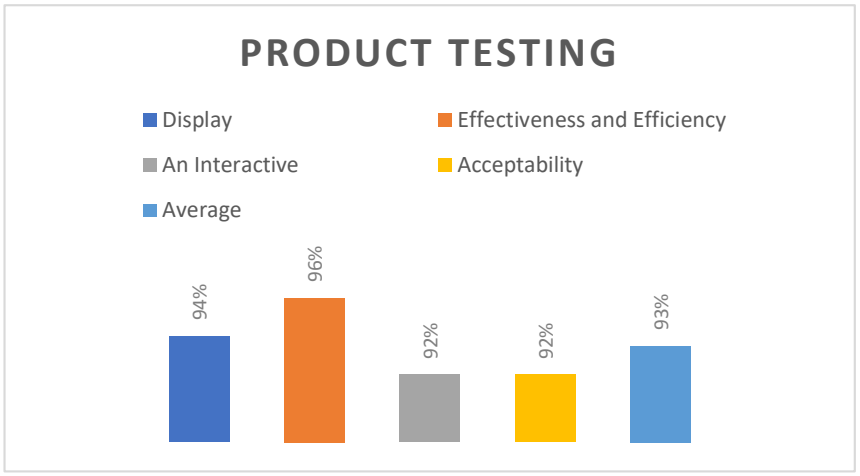

Figure 7. Results of Product Testing

The graph above shows the average score for the four aspects, each with 20 items, which is 93%. The appearance aspect consists of 4 items, with an average score of 3.8. The effectiveness and efficiency aspect consists of 6 items, with an average score of 3.8. The interactivity aspect consists of 6 items, with an average score of 3.7. The acceptability aspect consists of 4 items, with an average score of 3.7. Based on the user evaluation results, it was concluded that the interactive media developed using Google Sites for the CADD extracurricular activity is very good and deemed suitable for use as a training medium, with adjustments to the media and materials.

Discussion

The analysis of learners' needs and characteristics is a crucial initial stage in developing learning media. According to the ADDIE instructional design model by Branch (2009), the analysis stage identifies learning gaps and determines appropriate solutions based on user characteristics. In this context, the development of learning media aims to address students' needs for flexible, engaging, and easily accessible learning resources. This aligns with the research by Mislan & Santoso (2019), which states that understanding student characteristics is the key to the success of developing learning media and training media. The creation of appropriate training media, complete with module materials in the form of files (PDF), tutorial videos, and integrated practice questions, provides convenience and increases students' enthusiasm for learning, thereby helping them master the material (Shiddiqy & Saputra, 2022; Masdar et al., 2024; Regal & Widiasari, 2020). Therefore, the approach used in this study focuses on the utilisation of website-based technology, combined with materials in the form of files (PDF) and videos, and easy access through various devices without spatial or temporal limitations, thereby supporting self-directed and interactive learning.

The learning media developed consist of 13 modules in the form of files (PDF), two tutorial videos, and practice questions with three levels of difficulty: easy, medium, and difficult. The training material focuses on competencies in Mechanical Engineering, CAD, and Plastic Die Engineering, which are part of the students' primary programme expertise competencies. The presentation of the material, which combines text, images, and video, aligns with multimedia theory (Mayer, 2009), which emphasises the importance of simultaneously using verbal and visual elements in learning to enhance understanding and retention. The varied and structured design of the media also reflects the principles of cognitive load theory, presenting information in a way that does not overload students' working memory.

Given the developments made, it is necessary to evaluate the product in terms of interactivity, material accuracy, practicality, and suitability to needs (Kaniawati et al., 2023). To assess the feasibility of the developed media, validation was conducted by material and media experts. The validation results showed that the content aspect scored 92% and the media aspect scored 88%, both falling into the ‘Very Good’ category. This validation was based on indicators of content quality, alignment with the curriculum, clarity of presentation, and the effectiveness of the design. This study supports the formative evaluation theory proposed by Dick et al., (2015), which states that expert evaluation aims to ensure that the product meets quality standards before being implemented more widely. In addition to expert validation, a product trial was conducted with students and teachers, resulting in a 93% score in the ‘Very Good’ category, particularly in terms of interactivity, ease of use, and the usefulness of the media.

The results of this trial show that this website-based learning media has high user acceptance. From the perspective of Nielsen (1993) and usability theory, this media fulfils three main principles: learnability (ease of learning), efficiency (effectiveness of use), and satisfaction (user satisfaction). Teachers stated that this medium facilitates monitoring student engagement during training, while students felt it supports efficient independent learning. The medium's ability to provide immediate feedback through practice questions also strengthens student engagement in the learning process, which is the most important aspect of a student-centred learning approach.

Overall, the development of this training media is not only feasible but also relevant to current educational needs that demand critical thinking, collaborative skills, and digital literacy. The ease of access via digital devices allows teachers and students to stay connected throughout the learning process, including in extracurricular activities that often require flexible time commitments. Given the product's characteristics, supported by expert validation results and user evaluations, it is interpreted that the availability of this product will influence increased use of technological devices and enhance communication between teachers and students through the ease of teacher monitoring of student participation, thereby increasing student participation and supporting the success of training in extracurricular empowerment efforts (Amelia et al., 2025; Suleman & Idayanti, 2023; Wiryotinoyo et al., 2020).

CONCLUSION

Based on research and development of interactive media based on Google Sites, it can be concluded that: 1.) The developed product includes a Google Sites website accompanied by website usage instructions, an introduction accompanied by tips and tricks for Autodesk Inventor Professional 2024, project features, 2D sketches, standard 3D models, sheet metal 3D models, standard assemblies, welding, mould design, Inventor Studio, disassembly presentations, and 2D drawings in the form of module files (PDF), video tutorials, and practice questions integrated with the Google Sites website; 2.) The research and development process utilised the ADDIE development model 3.) The product has undergone expert validation of the media and materials, as well as testing by subjects, and is deemed suitable for use.

For further research, it is recommended to provide video tutorials for each material, with subtitles, to make it easier for students to understand and become interested in learning. Additional materials are needed based on the features available in Autodesk Inventor Professional 2024 or the latest version, starting from analysis features, cable and harness, tube and pipe, and surface design, as well as recommendations for creating more complex questions based on the latest competition guidelines, given its characteristics that always follow developments in the industrial world.

ACKNOWLEDGEMENT

Thanks to the Faculty of Engineering, State University of Malang, especially the Dean, Vice Dean 1, Head of the Department of Mechanical and Industrial Engineering, Coordinator of the Bachelor's Degree in Mechanical Engineering Education Study Programme, and Supervisors who have provided guidance and support to the author during the product development process and article writing. Thanks to Vocational High School Turen for permission and support during the research.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (14-25)
Online: http://journal.uny.ac.id/index.php/jitp

Articulate Storyline-based interactive media: An ADDIE-model development for algebraic operation learning

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ARTICLE INFO

Article History
Received:
8 July 2025;
Revised:
13 March 2026;
Accepted:
13 March 2026;
Available online:
31 March 2026.

Keywords
ADDIE model;
Algebraic operations;
Articulate Storyline;
Interactive media

ABSTRACT

Students' difficulties in understanding algebraic operations, particularly in translating contextual problems into symbolic expressions, highlight the need for instructional media that support visualisation, structured scaffolding, and active engagement. This study aimed to develop and evaluate Articulate Storyline-based interactive media for learning algebraic operations using the ADDIE model (analysis, design, development, implementation, and evaluation). Data were collected through expert validation sheets, student practicality questionnaires, and post-test assessments, and analysed using descriptive statistical techniques (mean scores and percentage distributions). The product was implemented in three stages: one-to-one testing (3 students), small-group testing (8 students), and a field trial involving 18 seventh-grade students. Expert validation indicated that the media was highly valid across content accuracy, contextual suitability, presentation quality, and instructional design. Practical results showed positive student responses regarding usability and engagement. The post-test mean score was 82, and all students achieved medium to very high performance, indicating potential improvement in conceptual understanding. This study contributes to mathematics education by providing an empirically validated multimedia design that integrates contextual animation, step-by-step symbolic visualisation, and interactive feedback to address abstraction challenges in algebra learning.

How to cite:
Arifin, S., Efriani, A., & Umayah, A. (2026). Articulate Storyline-based interactive media: An ADDIE-model development for algebraic operation learning. *Jurnal Inovasi Teknologi Pendidikan*, *13*(1), 14-25. https://doi.org/10.21831/jitp.v13i1.88167

INTRODUCTION

The transformation of education in the era of the Industrial Revolution 4.0 has positioned digital technology as a strategic foundation of 21st-century learning. The Education 4.0 paradigm requires instructional approaches that are adaptive, personalised, and engaging, supported by meaningful technological integration (Khanna et al., 2024; Moraes et al., 2023). The adoption of digital tools such as authoring platforms, learning management systems, and gamification-based media has been widely recognised as essential for improving student engagement and learning effectiveness (Alenezi et al., 2023; Chiappe et al., 2024). Empirical evidence further indicates that successful technology integration depends not only on infrastructure availability but also on pedagogically grounded instructional design and teacher readiness (Timotheou et al., 2023). These

findings suggest that systematic instructional development models must accompany digital transformation in education to ensure alignment between technological affordances and learning objectives.

This transformation particularly influences mathematics education due to its abstract and symbolic characteristics. As a discipline that emphasises logical reasoning and structural thinking, mathematics requires instructional strategies that bridge conceptual abstraction with meaningful representation (Loyens et al., 2023). Algebra, as a foundational topic in secondary education, demands students' ability to manipulate symbolic expressions and translate contextual situations into mathematical models. Research consistently documents persistent student difficulties in generalisation, symbolization, and procedural fluency in algebra (Chance et al., 2024; Oh & Han, 2022). Without adequate instructional support, these challenges often result in misconceptions and superficial understanding (Gilmore, 2023), particularly when classroom instruction lacks visual scaffolding and interactive engagement (Monteleone et al., 2023). Such conditions reinforce the need for interactive multimedia environments that facilitate conceptual visualisation, structured practice, and formative feedback.

Among various authoring platforms, Articulate Storyline has emerged as a promising tool for designing multimedia-based interactive learning environments that integrate text, animation, simulation, and automated feedback (Mand et al., 2024; Yorganci, 2022). Prior studies report that integrating Articulate Storyline in mathematics instruction improves conceptual understanding and classroom participation (Simarmata & Siregar, 2024), while also enhancing student independence and learning motivation (Putri et al., 2022). Additional evidence demonstrates its effectiveness in supporting conceptual mastery in higher-level mathematical topics such as calculus (Jazuli et al., 2024). Beyond mathematics, the validity and instructional feasibility of Articulate Storyline-based media have also been demonstrated in science learning at the junior secondary level, further affirming its cross-disciplinary applicability as an interactive learning platform (Setiawan & Rahman, 2025). Nevertheless, most of these studies primarily emphasise the product development and expert validation stages. Empirical examination of the practicality of classroom-based instruction and its measurable learning outcomes remains limited. A bibliometric review by Muhammad et al., (2023) confirms that research on Articulate Storyline has rarely progressed to systematic field implementation and impact measurement. Consequently, robust empirical evidence of its instructional effectiveness in authentic algebra classrooms at the junior secondary level remains insufficient.

Responding to this identified gap, the present study develops interactive mathematics learning media using Articulate Storyline to support algebraic form operations for junior secondary students, guided by the ADDIE development model (Branch, 2009; Julia et al., 2023). The study pursues three interrelated objectives. First, to evaluate the validity of the developed media through expert review to ensure content, design, and pedagogical alignment. Second, to examine its practicality based on student responses during staged classroom implementation. Third, to investigate its potential impact on students' conceptual understanding of algebraic operations as reflected in learning outcome measures. By extending prior development-oriented research toward systematic classroom evaluation and outcome-based analysis, this study contributes empirical evidence concerning the feasibility, usability, and instructional value of Articulate Storyline-based media. Furthermore, the research aligns with the implementation of the *Kurikulum Merdeka*, which emphasises contextualised and technology-enhanced learning practices (Ndari et al., 2023), thereby offering theoretical enrichment and practical guidance for reforming mathematics education.

METHOD

This study adopted an educational design research approach, employing the ADDIE instructional development model (Analysis, Design, Development, Implementation, and Evaluation) as its systematic procedural framework. The ADDIE model was selected over alternative development models due to its iterative, evaluation-driven structure that enables continuous refinement at each stage, its well-documented applicability in technology-integrated instructional

design, and its alignment with the quality indicators of validity, practicality, and learning impact targeted in this study (Branch, 2009; Jannah et al., 2023; Mukti et al., 2024). The research aimed to produce Articulate Storyline-based interactive learning media for algebraic form operations that meet established criteria for instructional validity and classroom practicality, while demonstrating potential improvements in student learning outcomes.

The study was conducted at Junior High School Number 2 Sungai Lilin during the first semester of the 2024/2025 academic year. Participants were selected through purposive sampling based on two primary criteria: students enrolled in Grade VII who were currently studying algebraic form operations as part of the national mathematics curriculum, and schools with basic digital infrastructure but that had not previously implemented interactive digital learning media in mathematics instruction. Expert validators comprised four individuals: three mathematics education lecturers with substantial experience in the design and development of digital learning media, and one practising mathematics instructional teacher with extensive classroom teaching experience at the junior secondary level. The implementation stage involved three sequential phases of student trials: a one-to-one trial (n = 3), a small group trial (n = 8), and a field test (n = 18 Grade VII students). Table 1 presents the full participant profile across all research stages.

Table 1. Research Participants at Each Stage

No.	Stage	Participant Profile	n
1	Expert Validation	Mathematics education lecturers (instructional design and digital media)	2
2	Expert Validation	Practising mathematics teacher (junior secondary level)	2
3	One-to-One Trial	Grade VII students	3
4	Small Group Trial	Grade VII students	8
5	Field Test	Grade VII students	18

Prior to data collection, formal written permission was obtained from the principal of Junior High School Number 2 Sungai Lilin. Informed consent was secured from all participating students and their parents or guardians. Participants were informed that their involvement was entirely voluntary, that they could withdraw at any time without consequences, and that all data collected would be used exclusively for academic research and reported in anonymised form.

Figure 1 presents the overall development procedure, illustrating the sequential, iterative flow through the five ADDIE stages.

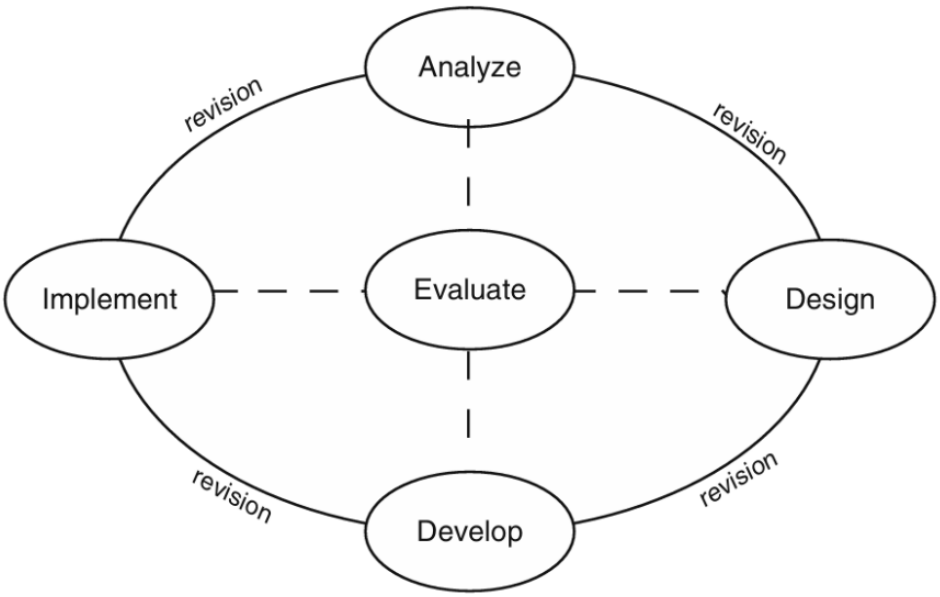

Figure 1. ADDIE Model Development Procedure in this Study

The development procedure followed the five ADDIE stages as illustrated in Figure 1. At the analysis stage, the researcher conducted a curriculum review of the *Kurikulum Merdeka* to identify

relevant learning competencies for algebraic operations, complemented by semi-structured interviews with the mathematics teacher and classroom observations to establish the instructional needs and learner characteristics profile (Wang, 2024). Identified needs included students' difficulties with symbolic abstraction, absence of visual scaffolding, and lack of interactive digital media in classroom practice. During the design stage, a detailed storyboard was developed to map content sequencing, interface navigation, and instructional interaction flows. Content was aligned with curriculum objectives and enriched with visual, animated, and contextual elements following multimedia learning principles (Mayer, 2009). Research instruments were also developed and validated at this stage (Sun, 2024).

During development, a media prototype was built in Articulate Storyline, incorporating flexible navigation, formative quizzes with automated feedback, contextual learning scenarios, audio narration, and character-based animations. The prototype was submitted to four expert validators using a structured Likert-scale rubric (1–4) covering four dimensions: content accuracy, visual presentation, contextual suitability, and instructional design innovation. Qualitative comments from validators informed iterative revisions to the media's language, interface, and technical features (Koszalka & Whorway, 2025; Timbi-Sisalima et al., 2024). To ensure consistency of evaluation across validators, an inter-rater agreement procedure was employed. Each validator independently assessed the media using the same structured rubric, and discrepant ratings were resolved through a structured discussion session to reach a consensual judgment.

The implementation stage consisted of three sequential phases. The one-to-one trial (n = 3) identified initial technical obstacles and evaluated navigation clarity. Following minor revisions, the small-group trial (n = 8) assessed the independent usability and coherence of interactive components. The field test (n = 18) was then conducted across four structured sessions of 2 × 40 minutes each, during which students accessed the media individually via mobile devices with minimal teacher guidance (Martín-Sómer et al., 2024). The evaluation stage incorporated both formative and summative components. Formative evaluation was embedded throughout each ADDIE stage to enable continuous media refinement (Shakeel et al., 2023), while summative evaluation assessed three quality indicators: validity, practicality, and potential impact on learning outcomes.

Three instruments were used for data collection, as summarised in Table 2. The expert validation sheet assessed four dimensions of media quality using a four-point Likert scale. The student practicality questionnaire measured perceived usability, navigation clarity, visual appeal, and content engagement. The post-test comprised items targeting conceptual understanding of algebraic form operations, administered following the field test phase. All instruments were developed based on established theoretical frameworks and reviewed for content validity by the expert validators before use.

Table 2. Research Instruments

No.	Instrument	Dimensions Assessed	Respondents	Scale
1	Expert Validation Sheet	Content accuracy, visual presentation, contextual suitability, and instructional design	4 Validators	Likert 1–4
2	Student Practicality Questionnaire	Usability, navigation, visual appeal, and content engagement	18 Students	Likert 1–4
3	Post-Test	Conceptual understanding of algebraic operations	18 Students	0–100

Data were analysed using descriptive statistical techniques, with results expressed as mean scores and percentage distributions. Media validity was determined by converting expert ratings into percentage scores, with a minimum threshold of 70% required for the media to be classified as valid (Adiastuti et al., 2025; Astuti et al., 2022). Practicality was similarly assessed through student questionnaire responses, with a minimum threshold of 60% required to classify the media as practical. Post-test scores were categorised into five performance levels as presented in Table 3. Given that this study represents an initial product development phase, inferential statistical procedures were not applied, and outcome findings are interpreted as indicative of potential instructional impact rather than causal evidence (Shakeel et al., 2023).

Table 3. Post-Test Score Classification Criteria

No.	Score Range	Category
1	86 < X ≤ 100	Very High
2	71 < X ≤ 86	High
3	56 < X ≤ 71	Moderate
4	26 < X ≤ 56	Low
5	Below 26	Very Low

RESULTS AND DISCUSSION

Results

The development of Articulate, a study on Storyline-based interactive learning media for algebraic form operations, using the ADDIE model, yielded findings across three quality dimensions: validity, potential effect on student learning outcomes, and practicality.

At the analysis stage, interviews with the mathematics teacher and review of learning documents confirmed that students experienced significant difficulties in understanding abstract algebraic concepts, particularly in relating algebraic symbols to contextual situations. Classroom instruction remained predominantly conventional, with no digital media available to support concept visualisation or active student engagement. These findings established the instructional need that guided subsequent design and development.

At the design stage, four main media components were planned in accordance with multimedia learning principles (Mayer, 2009), as presented in Figure 2.

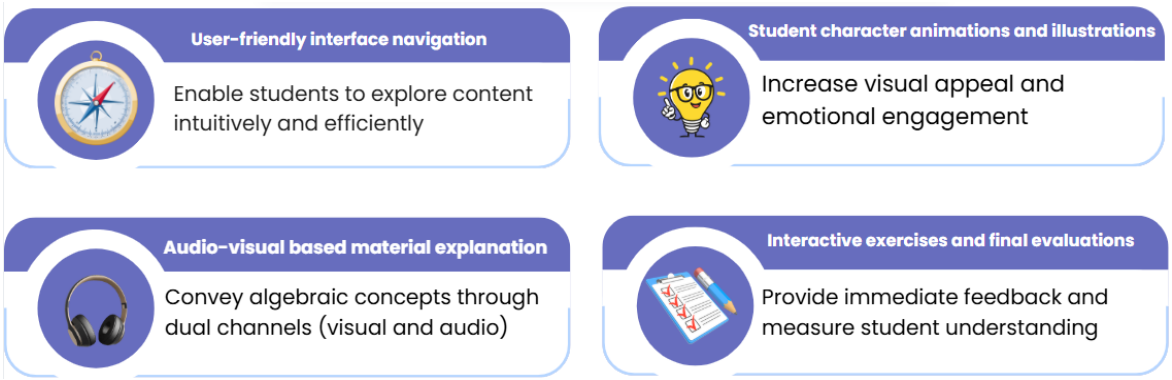

Figure 2. Design Components of Articulate Storyline-Based Interactive Learning Media

At the development stage, the media prototype was validated by four experts using a Likert-scale instrument (1–4) covering four dimensions: content feasibility, display presentation, context suitability, and media innovation. The validation results are presented in Table 4. The total average score of 3.73, equivalent to 93.25%, exceeds the minimum validity threshold of 70%, placing the media in the highly valid category across all assessed dimensions.

Table 4. Learning Media Validation Results

No.	Aspects Assessed	Average Score	Percentage (%)	Category
1	Content Feasibility	3.75	93.75	Highly Valid
2	Display Presentation	3.67	91.75	Highly Valid
3	Context Suitability	3.83	95.75	Highly Valid
4	Media Innovation	3.67	91.75	Highly Valid
Total Average		**3.73**	**93.25**	**Highly Valid**

The prototype of the developed media, as illustrated in Figure 3, demonstrates the integration of visual, audio, and interactive components across the main learning interface.

Figure 3. Interactive Media Development Prototype

At the implementation stage, the media was trialled in three sequential phases involving Grade VII students. The one-to-one trial (n = 3) identified initial technical obstacles and evaluated navigation clarity. The small-group trial (n = 8) assessed the independent usability and coherence of interactive components. The field test (n = 18) was conducted across four structured sessions of 2 × 40 minutes each, with students accessing the media individually via mobile devices. Figure 4 illustrates the implementation process across all three trial phases.

Figure 4. Implementation Stages: One-to-One, Small Group, and Field Test

Post-test results from the field test phase are presented in Table 5. The average post-test score was 82, placing the media in the very high category. The score distribution indicates that all students achieved at least the moderate performance threshold, with none falling into the low category.

Table 5. Distribution of Students' Post-Test Scores

No.	Score Range	Number of Students	Percentage (%)	Category
1	$86 < X \leq 100$	8	44.4	Very High
2	$71 < X \leq 86$	6	33.3	High
3	$56 < X \leq 71$	4	22.2	Moderate
4	$26 < X \leq 56$	0	0	Low
Total		**18**	**100**	-

At the evaluation stage, practicality was assessed through student response questionnaires. The average score of 74 out of a maximum of 85, equivalent to 87.06%, exceeds the minimum practicality threshold of 60%, placing the media in the practical category. Figure 5 presents the percentage distribution of student practicality score categories.

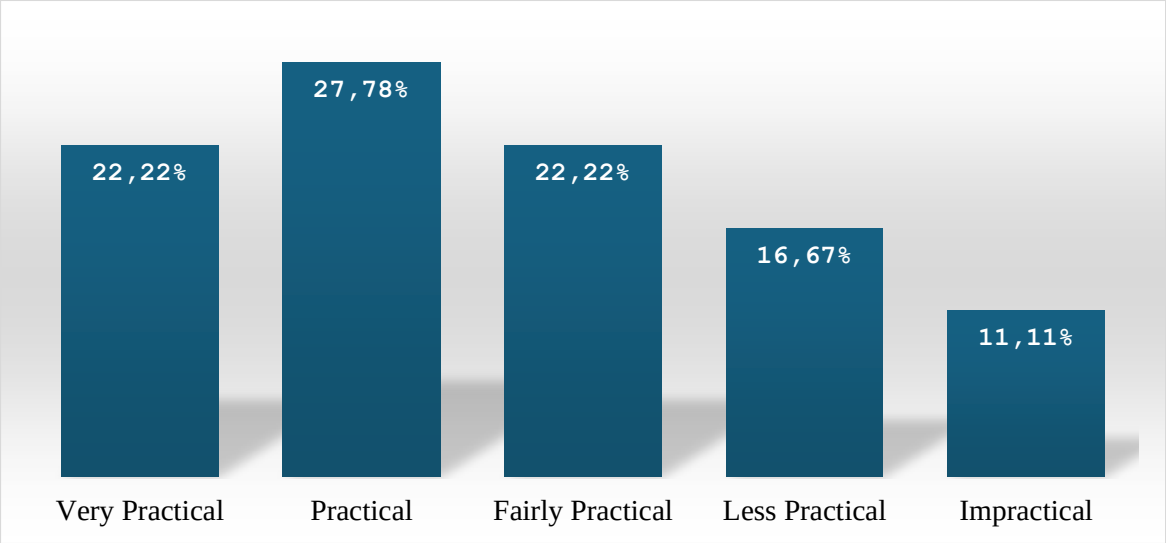

Figure 5. Percentage Distribution of Students' Practicality Score Categories

Discussion

The expert validation results, with an average score of 3.73 (93.25%) across all four assessed dimensions, confirm that the developed media meets established standards of instructional validity. This finding is consistent with those reported by Mukti et al., (2024) and Jannah et al., (2023), who similarly obtained highly valid ratings for Articulate Storyline-based media in mathematics learning contexts, and with Simarmata & Siregar (2024), who documented comparable validation outcomes in a junior secondary mathematics setting. The consistency of these findings across multiple studies suggests that Articulate Storyline, when developed through a systematic instructional design process, reliably produces media that meet content, visual, and pedagogical quality standards. Notably, context suitability received the highest rating among all assessed dimensions, indicating that the media successfully bridges abstract algebraic concepts with contextually meaningful representations and directly addresses one of the core learning difficulties identified during the analysis stage.

"Beyond mathematics, the validity and instructional feasibility of Articulate Storyline-based media have also been demonstrated in science learning at the junior secondary level, further affirming its cross-disciplinary applicability as an interactive learning platform (Setiawan & Rahman, 2025)."

The validity outcomes of this study are further grounded in established instructional design theory. Dick et al., (2015) emphasise that a valid instructional product must demonstrate strong alignment between content, learning objectives, and delivery strategies, a standard that the present media demonstrably meets across all assessed dimensions. Shakeel et al., (2023) affirm that rigorous expert validation is essential for ensuring the pedagogical soundness of digital learning media before classroom implementation, reinforcing the importance of the validation process undertaken in this study. Furthermore, Sun (2024) and Wang (2024) demonstrate that iterative validation cycles within the ADDIE model produce learning products that are more responsive to learner needs, a pattern clearly evident in the continuous refinement process that shaped the final media prototype.

The post-test results, with an average score of 82 and all students achieving at least the moderate performance level, indicate that the developed media has meaningful potential to support students' conceptual understanding of algebraic form operations. This is a significant finding. These results align with those of Julia et al., (2023), Jannah et al., (2023), and Mukti et al., (2024), who consistently documented improvements in mastery of mathematical concepts following the use of Articulate Storyline-based media, particularly in abstract symbolic topics where conventional instruction often falls short. The convergence of these findings across independent studies

strengthens the case that interactive multimedia environments, when designed with clear pedagogical intent, can effectively address the abstraction challenges that characterise algebra learning at the junior secondary level.

The media's effectiveness in supporting learning outcomes reflects the coherence between its instructional design and established cognitive learning principles. Mayer (2009) multimedia learning theory posits that instructional media integrating visual, auditory, and interactive channels reduces cognitive load through dual-channel processing and strengthens the integration of verbal and visual information. The present media operationalises these principles through step-by-step symbolic visualisation, contextual character animations, and automated formative feedback, collectively enabling students to construct conceptual schemata through repeated, structured interactions with the content. Davenport et al., (2023) further demonstrate that visualisation-based approaches in algebra learning help students build accurate mental representations of mathematical expression structures, while Chang & Lin (2024) report significant impacts of visual learning systems on conceptual understanding across diverse learner profiles, including those with learning difficulties. These theoretical and empirical perspectives confirm that the media's capacity to support conceptual understanding derives from the pedagogical coherence of its design, which systematically aligns visual scaffolding, interactive practice, and formative feedback to facilitate progressive concept formation in algebraic reasoning.

The practicality evaluation yielded an average score of 74 out of 85 (87.06%), exceeding the minimum threshold of 60% and indicating that the media was perceived as practical by the majority of students. This result is consistent with Putri et al., (2022), who reported positive student practicality responses to Articulate Storyline-based media in a mathematics learning context, and with Martín-Sómer et al., (2024), who similarly found that interactive media enhances learning efficiency and user satisfaction in specific subjects. Adiastuti et al., (2025) further corroborate this pattern, reporting validity ratings exceeding 90% and a practicality level of 91.33% for an ADDIE-developed digital learning material in a junior secondary mathematics context. The positive practicality perceptions observed in this study are attributable to the media's interface usability, navigation clarity, and visual engagement, which align with Alqurni (2023) assertion that intuitively designed interfaces reduce cognitive burden and improve user comfort. Hongsuchon et al., (2022) further demonstrate that media designs that facilitate active engagement and perceived accessibility directly contribute to increased motivation and learning outcomes, a pattern consistent with the predominantly positive student responses recorded in this study.

The convergence of high validity, strong learning-outcome indicators, and positive practicality perceptions collectively demonstrates that the developed media constitute a pedagogically sound and contextually applicable instructional resource for algebra learning at the junior secondary level. These findings collectively affirm that interactive multimedia environments, when grounded in systematic instructional design and informed by cognitive learning principles, can effectively address the abstraction challenges inherent in algebra instruction at this level.

These findings carry meaningful implications across theoretical, practical, and policy dimensions. Theoretically, the results strengthen constructivist and cognitivist frameworks for instructional media development, demonstrating that visually scaffolded, interactively structured, and contextually grounded media can facilitate conceptual understanding in abstract mathematical domains (Dick et al., 2015; Mayer, 2009). In practice, mathematics teachers can adopt this media as an alternative instructional resource that supports both classroom-based and independent technology-enhanced learning, in alignment with the contextualized and technology-driven pedagogical emphases of the *Kurikulum Merdeka* (Ndari et al., 2023). At the policy level, the findings underscore the importance of institutional support from schools and education authorities in enabling the systematic development and adoption of digital learning media that are responsive to learner characteristics and aligned with national educational technology priorities.

Several limitations of this study must be acknowledged, though they do not diminish its contributions. First, the trial was conducted with 18 students from a single school, limiting the generalizability of the findings to broader, more diverse educational contexts. Nevertheless, the results provide meaningful initial evidence of the media's instructional potential within the studied

setting. Second, the absence of a control group and a pretest means that the observed learning outcomes can be interpreted only as indicative of the media's potential instructional impact rather than as causal evidence of its effectiveness, highlighting the need for more rigorous experimental designs in subsequent research. Third, the practicality evaluation relied solely on student responses, without triangulation from teacher or educational technology expert perspectives, which limits the comprehensiveness of the usability assessment and the conclusions that can be drawn about the media's readiness for broader classroom adoption.

These limitations point to clear directions for future research. Subsequent studies are recommended to employ quasi-experimental designs with pretest-posttest control-group structures to provide more rigorous evidence of instructional effectiveness. Implementation should be extended across diverse school settings and learner profiles to strengthen the generalizability of the findings. In addition, teacher and expert perspectives should be incorporated into practicality evaluations to provide a more comprehensive assessment of media usability. Finally, responsive media designs optimized for varied digital device environments should be developed to address the technical compatibility issues identified in this study.

CONCLUSION

This study successfully developed Articulate Storyline-based interactive learning media for algebraic form operations using the ADDIE model and evaluated them across three quality dimensions. Expert validation confirmed that the media is highly valid in terms of content accuracy, contextual suitability, visual presentation, and instructional design, with a total average score of 3.73. Student responses indicated that the media is practical, with an average practicality score of 74, reflecting positive perceptions of usability and engagement. Post-test results demonstrated the media's potential to improve learning outcomes, with an average score of 82 and all students achieving at least the moderate category, indicating meaningful conceptual gains in algebraic operations.

This study contributes empirical evidence that systematically developed multimedia learning environments, grounded in the ADDIE model and informed by multimedia learning theory, can effectively address abstraction challenges in junior secondary mathematics education. These findings extend prior development-oriented research by demonstrating the feasibility, usability, and instructional value of Articulate Storyline-based media in authentic classroom settings.

Future research is recommended to employ quasi-experimental designs with pretest-posttest control-group structures to establish causal evidence of instructional effectiveness, extend implementation across diverse school contexts, incorporate teacher perspectives in practicality evaluations, and develop responsive media designs optimized for varied digital devices.

ACKNOWLEDGEMENT

The author would like to express sincere gratitude to the teachers and students of Junior High School Number 2 Sungai Lilin for their participation in developing and testing the learning media. Special thanks are also extended to the mathematics education lecturers and classroom teachers who provided expert validation and constructive feedback during the development process. This research would not have been possible without their valuable contributions and support.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (26-43)
Online: http://journal.uny.ac.id/index.php/jitp

An OBE-based e-module integrated with prophetic values: Enhancing statistical understanding, engagement, and character development

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ARTICLE INFO

Article History
Received:
25 October 2025;
Revised:
31 March 2026;
Accepted:
31 March 2026;
Available online:
31 March 2026.

Keywords
E-module; Outcomes-based education; Prophetic values; Statistics

ABSTRACT

Many students struggle to understand abstract concepts in Statistics because of limited contextual and interactive learning resources that connect theory to practice. Moreover, there is a lack of e-modules integrating prophetic values to support the vision of Universitas Muhammadiyah Metro. However, existing studies have not sufficiently integrated OBE with prophetic values in digital learning media for statistics, indicating a clear research gap. This study aims to develop an OBE-based e-module integrated with prophetic values for Statistics courses. The research employed an R&D method using the ADDIE model (analysis, design, development, implementation, and evaluation). The subjects were students of the Economic Education Study Program. Data were collected through interviews, expert validation and student response questionnaires, and analysed using descriptive quantitative and qualitative techniques. The results show that the e-module is highly valid (91.6%) and very practical (mean score = 4.3/5). Learning outcomes improved from an average of 62.5 to 83.7 ($p < 0.05$), indicating positive learning gains. This study provides contextual and methodological contributions by integrating OBE principles with prophetic values in digital learning design, and theoretical contributions in linking cognitive and character development in statistics learning. Future research should involve larger samples and longer implementation periods to assess affective outcomes better.

How to cite:
Vahlia et al., (2026). An OBE-based e-module integrated with prophetic values: Enhancing statistical understanding, engagement, and character development. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 26-43. https://doi.org/10.21831/jitp.v13i1.90807

INTRODUCTION

Higher education has a great responsibility in producing graduates who are not only academically superior but also able to adapt quickly to global dynamics. Education is not only an academic learning activity but also a continuation of the learning process and preparing students for the world of work (Mishra et al., 2020; Umar et al., 2024). The development of industry, technology, and community needs requires universities to continue innovating in how they organise learning. In this context, the Outcome-Based Education (OBE) approach is one of the strategic solutions to answer these challenges. This approach emphasises achieving learning outcomes as the main benchmark, integrating them into the curriculum, learning process, and assessment. The implementation of OBE aligns with the National Higher Education Standards (SN-Dikti) and serves as a reference for national and international accreditation (Kamahun & Indadihayati, 2023).

The OBE approach emphasises achieving learning outcomes through experience during the educational process (Kamahun & Indadihayati, 2023; Rahmawati & Wahyuni, 2024). The implementation of OBE affects all aspects of education, from planning and implementation to evaluation. Planning is an important factor in achieving success, including preparing teaching materials. Based on the results of internal audits conducted every even semester, it was found that most lecturers did not have OBE-based teaching materials before the start of lectures. Lecturers at the Faculty of Teacher Training and Education have received assistance in developing OBE-based learning devices, but have difficulty compiling them. In addition, the preparation of these teaching materials does not take into account student characteristics and has not undergone expert validation. Various previous studies have shown that OBE implementation focuses on aligning learning outcomes, learning activities, and assessment. However, most of these studies still emphasise curriculum and evaluation, while the integration of context- and student-needs-based teaching materials has not been studied in depth. Therefore, it can be concluded that the success of OBE is determined not only by curriculum design, but also by the quality and relevance of the teaching materials used in the learning process.

Statistics is one of the courses that plays an important role in developing data analysis skills and interpreting research results in the field of Education (Alem, 2020; Bromage et al., 2022; Henderson & Corry, 2021). All study programs at the Faculty of Teacher Training and Education include statistics courses taught to all students. Mastery of statistics enables students to understand, manage, and interpret data relevant to the learning process and various educational phenomena (Ediansyah et al., 2019; Romero & Ventura, 2020; Susbiyanto et al., 2019). However, in practice, many students struggle to understand the abstract concepts in educational statistics. This is due to the lack of contextual, interactive learning resources that link theory with practical applications in everyday life. Students' statistical problem-solving abilities are low and need improvement (Sriwahyuni & Maryati, 2022). Based on observations by Lecturers in Mathematics Education and Economics Education, many students arrive late to lectures because, at the Faculty of Teacher Training and Education (FKIP), lectures start at 07.30 this academic year. In addition, some students are less able to communicate, particularly in language style, and lack independence in completing assigned tasks.

The application of the OBE approach is one solution to overcome these problems. The OBE approach emphasises determining learning outcomes or achievements first, then designing learning methods and assessments to suit these outcomes (Davis & Knight, 2023; Weng & Chiu, 2023). This approach differs from the traditional method, in which lecturers first determine the topics to be taught and then identify the outputs. OBE focuses on improving students' learning experiences by ensuring learning outcomes are achieved through structured curriculum design (Kabeakan et al., 2024; Tenedero & Pacadaljen, 2021). OBE is strongly supportive of developing holistic student competencies, including technical, interpersonal, and work ethic skills. This approach is an important tool for improving the quality of education, institutions, and programs, and for supporting the development of students' work skills (Bandaranaike, 2018; Sun & Lee, 2020; Väisänen & Hirsto, 2020). Although numerous studies have examined the effectiveness of PjBL and e-modules in improving learning outcomes, there are still limitations in systematically integrating the OBE approach with statistical learning. Furthermore, most research still focuses on improving cognitive aspects, while values-based character development has not been a primary focus. Therefore, there is a significant research gap in the development of teaching materials that are not only oriented towards learning outcomes but also integrate spiritual values and character holistically.

An OBE-based curriculum focused on achieving outcomes can be implemented through the Project-Based Learning (PjBL) model. PjBL is considered an appropriate model to achieve educational goals in the 21st century because it integrates the 4C principles, namely critical thinking, communication, collaboration, and creativity (Marwa et al., 2024; Aliftika et al., 2019). Research conducted by Insyasiska and colleagues shows that PjBL encourages students to learn independently and seek information from various sources, such as experts, the surrounding environment, the media, and the internet. In addition, students are encouraged to collaborate in

teams to develop creative ideas, which are then realised as products (Insyasiska et al., 2017). According to Fitrianingtyas et al., (2023) and Herlina & Mugara (2021), project learning can change a person's disciplined character. Instilling character values is the goal of PjBL, which includes the planning and implementation process (Rifmasari et al., 2022). PjBL emphasises students' active involvement in completing real projects related to the material being studied. Through this approach, students not only gain theoretical understanding but also develop practical skills, such as data analysis, problem solving, and teamwork. PjBL can also increase independence (Ariyanto et al., 2022; Novalia et al., 2025). Interactive e-modules have been proven to improve students' cognitive abilities through pretest–posttest (Zakiyah & Dwiningsih, 2022). From various previous studies, there appears to be a gap, namely that there has not been much development of e-modules that integrate the OBE approach with prophetic values, statistics learning tends to be conventional, minimal contextualization, and has not utilized technology optimally and research related to the development of PjBL-based teaching materials in Statistics courses in the Institute for Teacher Training environment is still limited, especially those that combine aspects of Islamic character.

The development of prophecy-based e-modules is a strategic step in integrating Islamic values into the learning process and achieving the vision of Universitas Muhammadiyah Metro. Prophetic education is based on the concept of monotheism, morals, and social awareness. Monotheism teaches that God is the basis for all actions (Arman et al., 2025; Hamdi, 2023). The combination of PjBL with prophecy-based e-modules is expected to create holistic, meaningful, and relevant educational statistics learning aligned with the needs of the times. Through this research, it is hoped that learning products can be developed that not only improve students' understanding of educational statistics but also shape students with strong Islamic values in every aspect of their academic and professional lives. This research is based on a constructivist theoretical framework that emphasises that students actively construct knowledge through meaningful learning experiences. Furthermore, this approach is supported by self-regulated learning theory, which emphasises the importance of student independence in managing their learning, and by digital pedagogy theory, which emphasises the use of technology to create interactive and adaptive learning. The integration of these three perspectives provides the basis for developing an OBE-based e-module to enhance student engagement and learning experiences.

The development of an e-module based on OBE learning with prophetic values in Statistics courses is an important innovation that will improve learning quality. This approach focuses on specific, measurable, and relevant learning outcomes while integrating prophetic values, such as humanisation, liberation, and transcendence. This module is designed to address various challenges, including the lack of engaging digital teaching materials, insufficient integration of theory and practical application, and limited incorporation of prophetic values into learning. The development process begins with an analysis of student needs and a curriculum review, followed by the design of an interactive module, expert validation, and testing on small groups of students. Incorporating prophetic values into e-modules can promote ethical reasoning and moral decision-making among students, enriching the educational experience (Juliana et al., 2023).

This module is designed with interactive digital features, such as simulations, quizzes, and learning videos, and optimised for digital devices for easy student access. This e-module is expected not only to improve students' academic competence but also to foster prophetic values, making it a model for developing teaching materials in other courses. The use of a digital platform for e-modules can also increase social presence and interaction among students, further supporting a collaborative learning environment (Delıta et al., 2022; Lah et al., 2024; Kumar et al., 2023). The state of the art of this research includes interactive multimedia-based e-modules that are effective in improving student learning outcomes in elementary schools, especially in spatial geometry, with positive student responses that are strongly related to learning success (Alyusfitri et al., 2024). Problem-Based Learning (PBL)-based e-modules are effective in improving student learning outcomes by facilitating problem-solving skills and in-depth understanding of the material. These findings are similar to the research conducted, because both use e-modules as innovative learning media to improve the quality of learning outcomes (Ali et al., 2023). Development of electronic modules (e-modules) based on problem-based learning to improve critical thinking skills (Leny et

al., 2024). Developing e-modules on socio-scientific issues, integrated with verses of the Qur'an, to build a profile of Pancasila students, emphasising the strengthening of moral and social values in learning (Zarkasih et al., 2023). Development of e-modules based on project-based learning to improve the quality of learning in vocational schools. The findings show that this e-module can help students be more active and involved in the learning process with a more practical and applicable approach (Hanif & Santosa, 2023; Rahmatika et al., 2021). Based on the description above, the novelty of this study lies in the simultaneous integration of three approaches: the OBE learning approach, the PjBL model, and prophetic values expressed through Statistics e-modules. This study also uses a development approach grounded in the contextual needs of FKIP students, especially in shaping a graduate profile with an Islamic character, academic competence, and readiness to face the challenges of the times.

Based on the background, the formulation of the problem in this study is how the students' needs for OBE-based Statistics teaching materials, accompanied by prophetic values, are met, how the process of developing OBE-based Statistics e-modules and prophetic values using the PjB model is conducted, and what the level of validity, practicality, and effectiveness of OBE-based Statistics e-modules accompanied by prophetic values is. Therefore, this study aims to analyse students' needs for OBE-based Statistics teaching materials that incorporate prophetic values. Moreover, develop OBE-based Statistics e-modules and prophetic values using the PjBL model, and measure the validity, practicality, and effectiveness of these e-modules accompanied by prophetic values. This research is also expected to help lecturers design learning that is oriented towards outcomes and integrated with values, as well as to support the holistic development of student competencies, including cognitive, affective, and ethical aspects, in higher education. This research also has the potential to support the transformation of higher education toward more contextual, meaningful, and student-centred learning. Furthermore, the results are expected to serve as a reference for policymakers in developing an OBE-based curriculum that aligns with Islamic values and encourages increased digital literacy among students and lecturers.

This research contributes to the development of an OBE-based teaching material model integrated with prophetic values through the Project-Based Learning (PjBL) approach. The main contribution of this research lies not only in the development of an e-module product but also in the conceptual integration between the OBE approach, project-based learning model, and prophetic values within a single learning framework. Thus, this research enriches the study of innovative learning design that is not only oriented towards learning outcomes, but also towards character and value formation.

METHOD

This research was conducted in 2025 at the Faculty of Teacher Training and Education (FKIP) of Universitas Muhammadiyah Metro, with implementation spanning several stages from product development to evaluation, from January to March 2025. This study uses the Research and Development (R&D) methodology with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) as explained by Isnaini et al., (2024), which was chosen because of its ability to provide a systematic, structured, and iterative framework in developing new products or improving existing products. This approach is designed to produce a statistics e-module that integrates learning content, Project-Based Learning (PBL) -based pedagogical strategies, and prophetic values. This study used a development research design with a quasi-experimental approach during the implementation phase to test the product's effectiveness. This design was chosen because it not only produced a learning product but also empirically tested its impact on student learning outcomes in a real-world context.

Furthermore, this study ensures methodological rigour by incorporating both formative and summative evaluation processes throughout the ADDIE stages. Formative evaluation was conducted during the analysis, design, and development phases through expert validation and small-group trials to identify initial weaknesses in the product and make necessary revisions. Meanwhile, a summative evaluation was conducted during the implementation phase using a quasi-experimental design to assess the effectiveness of the developed e-module. This combination of

iterative development and empirical testing enhances the validity of the research findings, ensuring that the resulting product is not only theoretically sound but also practically applicable in real learning environments.

An overview of the steps in developing the modified ADDIE model for this study is presented in Figure 1.

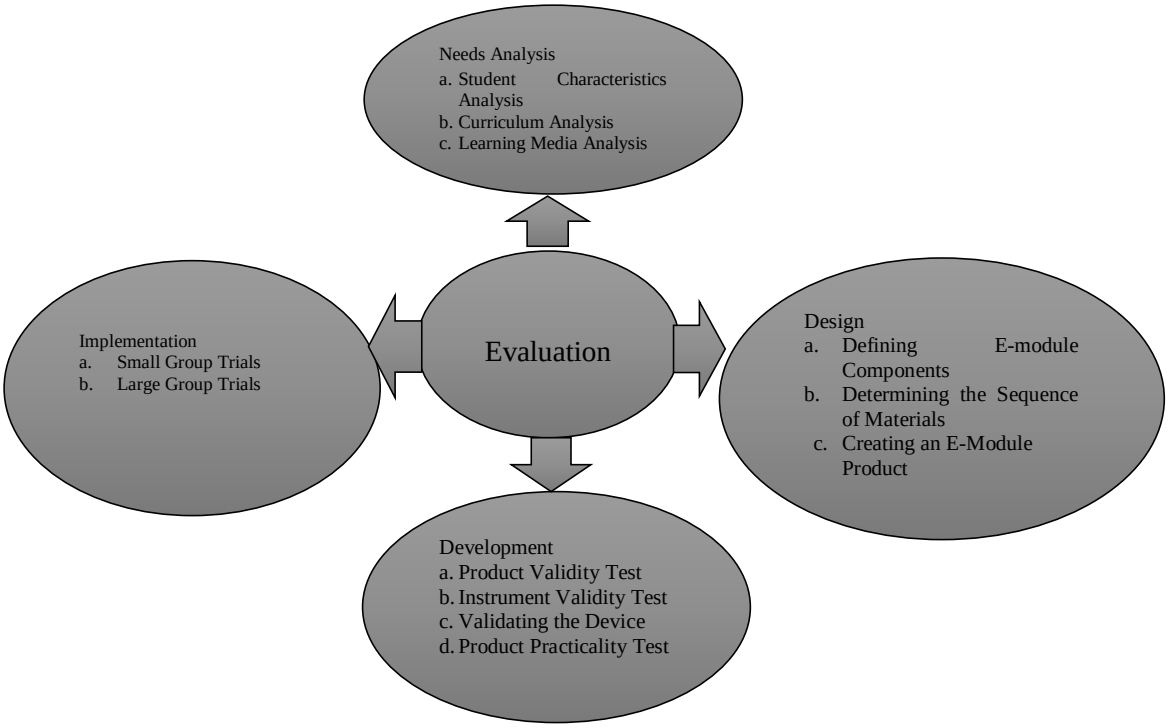

Figure 1. Steps in Developing the ADDIE Model

The ADDIE development model consists of five interrelated stages, namely Analysis, Design, Development, Implementation, and Evaluation. In the Analysis stage, needs identification is carried out, including determining problems and evaluating existing teaching materials to ensure the accuracy and relevance of the information. Next, the Design stage involves comprehensive planning, from conceptualisation to finalisation of the product design, accompanied by continuous revision to improve quality. At the Development stage, the product is developed and tested for validity through student trials and formative evaluations to assess its practicality and feasibility. After that, the Implementation stage involves applying the validated product to the real learning process. Finally, the Evaluation stage is carried out continuously at each stage of development to ensure the resulting product meets the established quality standards.

Data Collection Instruments

The research data collection instruments include interview guidelines, expert validation questionnaires, and student practicality questionnaires for product quality evaluation. Validation uses modified criteria adjusted to the characteristics and objectives of the research to produce valid and reliable data, and testing is conducted by material experts, media experts, and practicality questionnaires listed in Table 1.

Table 1. Data Collection Instruments

No.	Dimensions		
	Content	**Media**	**Practicality**
1	Content Quality	General Quality	Scheme
2	Language Quality	Special Quality	Content and Materials
3	Integration of OBE Models	Media View	OBE Model Usage Format

This study uses interviews and questionnaires to assess the validity, practicality, and feasibility of the product. Interviews explore the needs of related parties, while questionnaires measure user perceptions of the ease, relevance, and efficiency of the product. Small-group trials with 15 students from the Mathematics Education Study Program: if the product meets the practical criteria, it is considered suitable for use in learning. The next stage is the effectiveness test involving 80 students, consisting of 10 students each, taken by random sampling in the Mathematics, Biology, Economics, Physics, Primary School Teacher Education, History, English, and Guidance and Counselling Study Programs to identify product deficiencies, with the results used as a basis for improvement so that the product supports learning optimally. The sample size for the small-group trial was determined by the principle of formative evaluation in development research, which generally involves a small number of participants to identify initial product issues. Meanwhile, the sample size in the effectiveness test (n = 80) was considered sufficient for parametric statistical analysis, as previous research indicates that a large enough sample is necessary to achieve sufficient statistical power to detect significant differences between groups (Besekar et al., 2024).

This study uses data analysis to evaluate the validity, practicality, and effectiveness of the OBE-based E-module accompanied by prophetic values. Data analysis begins with normality and homogeneity tests to ensure normal distribution and homogeneous variance (Zaitun et al., 2025). Before conducting the hypothesis test, the statistical assumptions were tested, including normality with the Shapiro-Wilk test and homogeneity with the Levene test. The test results showed that the data were normally distributed and had homogeneous variance, meeting the requirements for parametric analysis. Then continues with t-tests, including paired t-tests to compare pretests and posttests within groups, and independent t-tests to compare posttest results between the two groups (Sukarelawan et al., 2024). This approach provides empirical evidence regarding the effectiveness of learning media. All data analysis was carried out at the 0.05 significance level using statistical software, ensuring results could be interpreted objectively and quantitatively.

RESULTS AND DISCUSSION

Results

Theoretically, these findings strengthen the integration between the Outcome-Based Education (OBE) approach and constructivist theory in learning. OBE emphasises the achievement of measurable learning outcomes, while constructivism emphasises the process of knowledge construction through experience. The integration of the two in this e-module demonstrates that outcome-oriented learning is more effective when supported by meaningful, contextual learning activities. Furthermore, these findings are also relevant to the theory of self-regulated learning, which emphasises the importance of student independence in managing the learning process.

This study aims to develop an OBE-based e-module combined with prophetic values in statistics courses at the FKIP of Muhammadiyah Metro University. At the analysis stage, students' needs for relevant and meaningful Statistics teaching materials were identified. The results of interviews and observations showed that many students had difficulty understanding abstract concepts in Statistics because the teaching materials used were not contextual, OBE-based, or aligned with prophetic values.

In addition, most lecturers at FKIP lacked validated OBE-based teaching tools, even after receiving training. The mismatch between student characteristics and conventional learning approaches was also a problem. The main finding at this stage was the unavailability of statistics teaching materials that aligned with the OBE approach and prophetic values. This was exacerbated by the lack of support for digital learning resources that could bridge theory and practice. The contributing factors included the limitations of the teaching tools used by lecturers, students' suboptimal technological literacy, and the lack of teaching materials designed around learning outcomes. A comprehensive needs analysis approach based on field data, the scope of analysis is

still limited to one institution. These results align with research by Qomaria & Wulandari (2022), which found that statistics learning requires support from context-based learning resources.

At the design stage, the e-module is developed systematically, with the OBE principle guiding the compilation of content based on learning outcomes. The module is designed with measurable outcomes, interactive visual planning, and the involvement of lecturers and expert teams since the design stage. Compiling the cover design and layout of the e-module to be created. The module's learning activities combine individual assignments, group discussions, and value reflections. The module's design is adaptive to the user's context and integrates cognitive and affective dimensions.

The results of the e-module development show that the product design and testing stages successfully integrated OBE principles and prophetic values into statistical learning materials. Based on data from the initial trial, most students found this e-module very helpful in clarifying their understanding of statistical concepts. The validation results conducted by material and media experts showed that the product met the quality standards set for OBE-based e-modules, as presented in Table 2. The Results of the OBE and Prophetic-Based E-Module Trials are shown in Table 2 as follows:

Table 2. Results of the OBE and Prophetic-Based E-Module Trial

No.	Rated aspect	Average Score
1	Content Quality	4.5
2	OBE Model Integration	4.7
3	Prophetic Value	4.6
4	Ease of Use of E-Modules	4.3

Based on the data in Table 2, the developed e-module has successfully fulfilled all the desired aspects, including academic content, OBE models, and the integration of prophetic values into statistical materials. The results of developing OBE-based e-modules that incorporate prophetic values indicate a positive response from students. This finding aligns with previous studies that indicate that the use of outcome-based learning models, such as OBE, can improve students' understanding in technical and theoretical courses (Hanafiah et al., 2024). In addition, the application of prophetic values has a positive impact on the formation of student character, consistent with the goal of Universitas Muhammadiyah Metro to produce individuals who are academically intelligent and have strong moral values.

After the module was declared valid and practical, the implementation stage was carried out on students from various study programs at the University. The learning process was divided into four sessions, each involving real, context-based tasks and the integration of prophetic values. Students were active in discussions, data analysis, and reflection on values in each meeting. The main finding at this stage was that implementing the e-module increased student engagement and encouraged more meaningful independent learning.

These results strengthen the findings of Himmah et al., (2024) and Rahayu et al., (2023) which show that the e-module is effective in encouraging active participation. The main difference is the integration of the prophetic value dimension, which has not been widely carried out in previous studies. The practicality test was measured using a questionnaire administered to 15 students who participated in the module trial. The questionnaire results showed that the majority of students found this e-module very practical and easy to use. The average score for the practicality aspect was 4.3, as shown in Table 3. This indicates that the developed e-module is very suitable for use in statistics learning activities.

Table 3. E-Module Practicality Questionnaire Results

No.	Rated aspect	Average Score
1	Ease of Access to E-Modules	4.4
2	Clarity of Instructions for Use	4.2
3	Use of E-Module Features	4.3
4	Ease of Application of Prophetic Values	4.1

Based on Table 3, the practicality test of this e-module is the primary factor in determining its success in the learning process. The results of this study are in consistent with findings from various studies, which show that e-modules designed with attention to user needs and convenience are more accepted and effective in supporting the learning process (Ombili at al., 2024). Ease of access to materials and understanding of instructions are important factors that ensure optimal use of this module by students.

The evaluation stage was carried out by testing effectiveness using a pretest and posttest with 80 students. The test results showed a significant increase in student scores (the average increased from 62.5 to 83.7; $p < 0.05$). In addition, the t-test results showed a significant difference between the pretest and posttest scores ($p < 0.05$), indicating that this OBE-based e-module is effective in improving students' understanding of the statistical material. The significant increase in pretest-to-posttest scores indicates that the OBE-based e-module is effective in improving students' understanding of statistics courses. This finding is consistent with research by Hidayat et al., (2024) and Probowati et al., (2023), which show that e-modules designed with an outcome-based approach can improve students' understanding and skills, especially in courses that require in-depth data analysis and interpretation.

The significant improvement in scores not only demonstrates differences in learning outcomes but also indicates that OBE-based e-modules provide a more structured, outcome-oriented learning experience. Conceptually, this can be explained through constructivist theory, which holds that students construct understanding through active engagement in project-based activities and reflective practice. Thus, the improvement in learning outcomes is not simply a result of media use, but rather the result of the interaction among instructional design, learning activities, and student engagement. In addition to significance testing, the magnitude of the e-module's impact can also be assessed through its effect size. Based on Cohen's d calculations, the effect sizes were in the moderate to high range, indicating that the improvement in learning outcomes was not only statistically significant but also practically meaningful. This indicates that the e-module had a significant impact on improving student understanding.

The learning activities in this study are organised into four main sessions, each ending with a quiz to evaluate students' learning. Each session is designed to refer to the OBE principle and synergistically combined with prophetic values, namely humanisation, liberation, and transcendence, to shape character and deepen students' understanding of statistical concepts. In the first session, students are introduced to the basic concepts of statistics and types of data. Learning begins with an introduction to the e-module and OBE-based learning structure. Students participate in group discussions to analyse simple data. The value of humanisation is emphasised by understanding that data represents diverse social realities.

The main goal of this meeting is for students to recognise and explain data types and their roles in statistical studies. The second session focuses on understanding measures of data centralisation, such as mean, median, and mode. Students practice calculations both manually and using technology, in the context of case studies. The value of liberation is instilled by providing students with space to express their opinions and analyse freely. At the end of the session, students are given individual assignments using real data to strengthen their understanding of data centralisation. In the third session, students begin exploring data distribution measures such as range, variance, and standard deviation. Learning is carried out through real-life case-based exercises, such as social and economic inequality.

In this activity, the value of transcendence is emphasised by inviting students to link statistical calculations to a broader social context, enabling them to interpret data not only technically but also ethically and morally. The fourth session focuses on students' ability to interpret and visualise data, including making graphs and compiling simple statistical reports. Activities are carried out in groups, and each group presents the results of its analysis to the class. In this session, the values of integrity and cooperation are key, emphasising honesty in data processing and collaboration in report compilation. In closing, students take an evaluation quiz in the form of a description that aims to measure conceptual understanding, critical thinking skills, and the application of prophetic values in solving statistical problems. This quiz is also a form of

formative assessment to measure achievement of OBE-based learning outcomes. The design of the learning process is shown in Table 4 as follows:

Table 4. Learning Process Design

No.	Learning Topics	Learning Activities	Integrated Prophetic Values	Learning Outcomes (OBE)
1	Basic Concepts of Statistics & Data Types	Introduction to e-modules- Exploration of data types- Small group discussions	Humanisation (respecting differences in data and respondent backgrounds)	Understanding the basics of statistics and data classification
2	Measures of Central Tendency (Mean, Median, Mode)	Manual & digital calculation simulation- Case-based individual assignments	Liberation (freedom to think and analyse based on the context of real cases)	Using measures of central tendency in simple statistical analysis
3	Measure of Data Spread, Standard Deviation	Data analysis through e-modules-Group reflection & Q&A	Transcendence (linking analysis to social impact).	Interpreting data distribution in the context of social problems
4	Data Interpretation & Visualisation	Preparation of simple statistical reports - Group presentation	Collaboration and integrity (working together on data truth and honesty)	Presenting data in graphical form and summarising the analysis results
5	Understanding Evaluation	Individual quiz based on descriptive questions- Final reflection on the use of e-modules	-	Measuring the achievement of students' cognitive competencies and critical attitudes

Table 4 shows that OBE-based learning achievements were implemented. However, several students had difficulty accessing technology to use the e-module optimally due to limited internet connectivity, and they needed time to get used to the interactive OBE e-module. In addition, not all students can think critically about statistical data analysis and the integration of Prophetic Values; some remain confused about interpreting Prophetic Values in the context of statistical analysis. Lecturers began to focus on conducting short training on how to use e-modules optimally at the beginning of the lecture, providing a guide to using the module in the form of videos or PDFs that are easily accessible, and providing technical support during the learning process. Students are not focused solely on final learning outcomes; they are also directed to develop measurable competencies. With OBE-based E-modules, active and independent learning can be encouraged, where students are trained to learn through real cases and value reflections. The OBE model is easy to adjust to the Graduate Profile: Because it is achievement-based, materials and approaches can be aligned with moral and intellectual competencies. The following table of contents displays the OBE-based e-module, accompanied by the prophetic values presented in Figure 2.

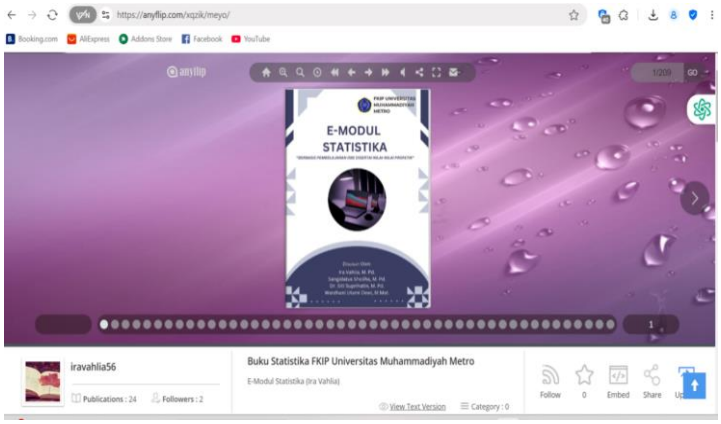

Figure 2. Table of Contents View

Based on Figure 2, the table of contents of the Statistics book closely matches the principles of Outcome-Based Education (OBE) learning. The OBE approach emphasises the achievement of clear, measurable, and relevant learning outcomes to real-world needs. This is reflected in the sequence of chapters in the book, which begins with an introduction to basic statistical concepts, such as definitions, types of data, and population-samples (Chapter I), followed by material on measurement scales (Chapter II), which are an important foundation in data analysis. This stage aligns with the OBE process, which begins by determining initial achievements, such as understanding basic concepts.

Furthermore, this book presents advanced topics in a gradual, systematic manner, such as central symptom analysis and deviation measures (Chapters III and IV), which indicate the direction of learning towards mastering descriptive analysis competencies. The progressiveness of this material aligns with the OBE principle, which encourages tiered learning based on skill complexity. Not only that, topics such as multiple correlation (Chapter V) and simple linear regression (Chapter VI) are application-oriented, requiring students not only to understand the theory but also to process and interpret data in a practical context.

Each chapter ends with a section of practice questions, indicating that this book has also implemented the principle of continuous evaluation, as emphasised in the OBE approach. This evaluation plays an important role in measuring the achievement of learning outcomes, both formatively and summatively. The existence of these practice questions allows students to gauge their mastery of the material being studied and provides lecturers with feedback to adjust learning strategies. With this structure, this book as a whole can be said to support the OBE-based learning approach. Each chapter is arranged in a logical, pedagogical sequence that allows students to develop knowledge, skills, and attitudes in measurable ways. The content of the material related to prophetic values is presented in Figure 3.

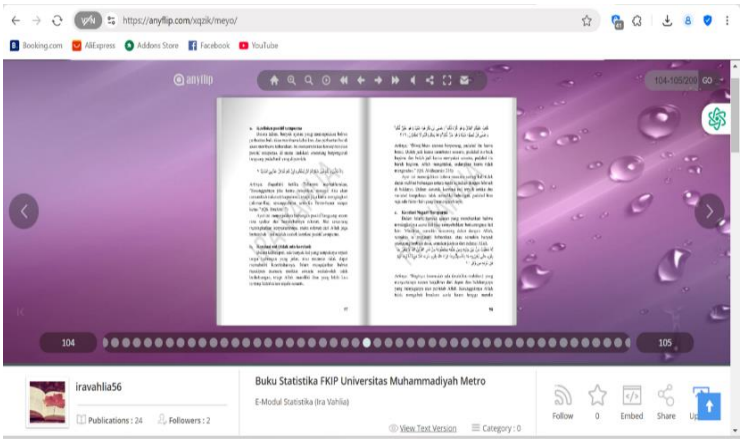

Figure 3. Display of Module Integration with Prophetic Values

In Figure 3, the module content links the concept of recording good deeds in the Qur'an with the principles of statistics, thereby explicitly integrating prophetic values into learning. The quoted verses emphasise that all human deeds, no matter how small, are carefully and systematically recorded. This aligns with the basic principles of statistics, which demand precision, honesty, and accuracy in recording and processing data. The value of transcendence is reflected in the awareness that scientific activities, such as data collection and analysis, are basically a form of moral responsibility that also has spiritual value. Students are directed to view statistical activities not merely as technical, but as a form of scientific mandate that reflects integrity and accountability before God. Thus, integrating prophetic values into statistics learning, as shown in this section, not only adds a religious dimension to higher education but also instils important character values in students. Statistics is taught not only as an analytical tool but also as a vehicle for forming academically intelligent, morally honest, and sensitive human beings who understand and value human and social values. This approach strengthens the role of higher education in producing graduates who are not only competent but also have integrity and moral values.

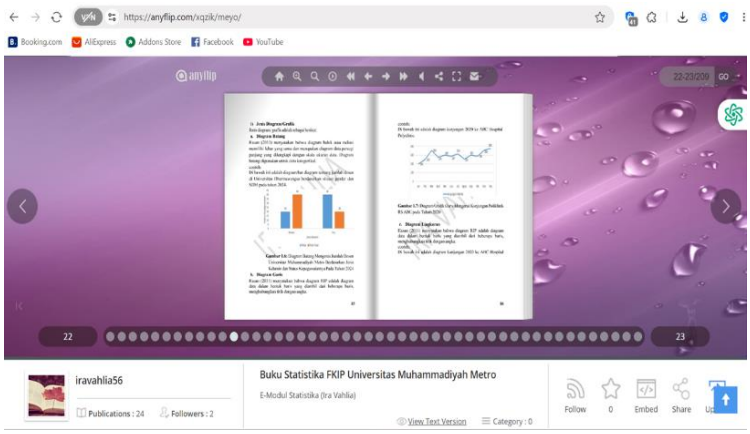

Figure 4. Worksheet View

Based on Figure 4, the displayed assignment sheet demonstrates the practical application of statistical analysis concepts, particularly ANOVA and post hoc follow-up tests, in educational research to examine the influence of various learning media on student learning outcomes. When aligned with the principles of Outcome-Based Education (OBE), this assignment is highly relevant because it encourages students to achieve concrete, measurable, and context-specific learning outcomes. This assignment is not only oriented toward mastering theory but also toward direct application to educational problems. First, in terms of task formulation, students are directed to calculate the average and variance, conduct ANOVA tests, and interpret the results of group differences. This activity encourages high-level thinking skills such as analysing and evaluating data. Thus, this assignment accommodates high learning outcomes according to Bloom's taxonomy, especially at the analysis and evaluation levels. This aligns with the OBE principle, which emphasises that learning must be oriented towards specific and meaningful final achievements.

After three meetings, the effectiveness test continued using a paired-samples t-test, showing a significant increase in students' pretest-to-posttest scores after using the E-Module. The significance value (Sig. 2-tailed) of 0.000, which is smaller than 0.05, indicates that the use of the OBE-based E-Module integrated with prophetic values has been statistically proven effective in improving student learning outcomes in the Statistics course. The average pretest score, previously 51.2, increased to 85.2 during the posttest. These results indicate that a learning approach that combines achievement orientation with strengthening of prophetic values can encourage greater understanding of the material while forming student character in an integrated manner.

The assignments in the E-module invite students to work with real data. Students are not only asked to perform statistical calculations, but also to draw conclusions and provide recommendations regarding the most effective learning methods. This approach shows that learning is not only focused on academic results, but also on data-based decision-making, which is very much needed in professional practice in education. The use of software such as SPSS, Excel, or Minitab, as suggested in the assignment instructions, emphasises the importance of mastering technology as part of 21st-century skills. This strengthens the assignment's alignment with the OBE principle, which encourages students to master relevant and applicable skills in the world of work. The ability to use digital statistical tools shows students' readiness to face challenges outside the academic world.

This study has a limited sample of only one college, so generalisation is still limited. Short Implementation Time: Four meetings are insufficient to assess the long-term impact of integrating prophetic value. In addition, the instruments used are limited because not all affective aspects (prophetic character) can be measured quantitatively. Although the results show significant improvements, generalising these findings should be approached with caution, as the study was conducted at a single institution with specific student characteristics. Therefore, these results are best interpreted in a similar context and require further testing on a broader population. The validity and practicality aspects of the module are shown in Table 5.

Table 5. Validity and Practicality Aspects

No.	Rated Aspect	Result	Category
1	E-Module Validity	91.6%	Very Valid
2	Practicality of E-Module	4.3	Very Practical

Based on Table 5, the developed e-module demonstrated high feasibility for implementation in learning activities. A validity score of 91.6% indicates that the content, design, and integration of OBE principles with prophetic values met the expected quality standards. This indicates that the e-module is appropriate in terms of material accuracy, instructional design, and relevance to learning outcomes. Meanwhile, a practicality score of 4.3 (out of 5) reflects that the e-module is easy to use, accessible, and supports the learning process from a student perspective.

Furthermore, the findings indicate that students have begun to internalise prophetic humanisation values, as evidenced by their reflections and responses to the final assignment. Although not all affective aspects can be measured quantitatively, qualitative indicators indicate positive character development. Furthermore, the use of this e-module increased student engagement and responsibility, particularly in discussions and assignments grounded in real-world contexts. This indicates that this learning approach not only enhances cognitive understanding but also supports the development of students' affective and ethical competencies.

Discussion

The results of the study show that the OBE-based e-module, which integrates prophetic values, has high validity and practicality and is effective in improving student learning outcomes. This finding aligns with the research by Zakiyah & Dwiningsih (2022), which showed that the use of interactive e-modules significantly improved student learning outcomes, as evidenced by pretest and posttest scores. This reinforces the belief that interactive digital learning media can help students understand abstract concepts more conceptually. Theoretically, this finding is supported by the OBE approach, which places learning outcomes at the centre of learning design, and by constructivism, which emphasises that knowledge is built through meaningful learning experiences. In this context, the developed e-modules not only present material but also provide real-life case-based activities that enable students to construct understanding actively. The integration of prophetic values, emphasising the human dimension, freedom of thought, and spiritual awareness, strengthens the learning process by offering meaning beyond mere cognitive aspects.

The success of this research can be explained through a logical cause-and-effect relationship. When students are provided with contextual learning experiences through project-based e-modules, they no longer accept concepts abstractly but relate them to reality. This leads to increased learning engagement. High engagement then fosters independence and responsibility in completing assignments. Ultimately, this leads to improved learning outcomes and a deeper understanding. Thus, the e-module serves not only as a medium but also as a facilitator of students' learning styles.

The gradual implementation of the learning process over four sessions also reinforces these findings. In the first session, students began to understand basic statistical concepts through simple data-based discussions, fostering an awareness that data represent social reality. At this stage, engagement began to develop, although it was still in the adaptation phase. The second session demonstrated improved analytical skills through calculation activities and case studies, which allowed students to think critically. In the third session, students began to interpret data more deeply and relate it to the social context, making learning more meaningful. Ultimately, in the fourth session, through an effectiveness test, a significant improvement in learning outcomes was observed, demonstrating that the systematically designed learning process had a tangible impact on student achievement.

The findings of this study align with several studies demonstrating the effectiveness of digital-based e-modules in improving learning outcomes (Deotare et al., 2026; Yang et al., 2026). Research by Muhali & Asy'ari (2026) and Lee et al., (2025) found that a project-based approach can improve critical thinking and problem-solving skills. In addition, research by Gayatri & Karman, (2026) and Luber et al., (2026) confirms that technology integration in learning, including digital-based learning, can improve analytical skills. Other research by Cheng & Weatherly (2025)

and Osiesi & Blignaut (2025) also shows that the use of digital technology in education improves learning outcomes and 21st-century skills. However, this study has the advantage of integrating prophetic values that have not been widely studied in the context of digital-based learning.

Analytically, the improvement in learning outcomes in this study occurred due to the integration of the OBE approach, experiential activities, and the use of digital media. This aligns with other research suggesting that e-modules equipped with interactive elements, such as simulations and visualisations, can increase student engagement and conceptual understanding. Furthermore, research on the development of ADDIE-based e-modules also shows that valid, practical, and effective media can significantly improve learning outcomes, with statistical test results indicating a pretest-posttest difference (sig < 0.05) (Pratamadita & Dwiningsih, 2022). Compared with previous research, this study's results have the advantage of integrating prophetic values into e-modules. While previous research generally focused solely on cognitive aspects and improving learning outcomes, this study integrates character aspects into the learning process. This finding is supported by research showing that the use of digital-based e-modules not only improves conceptual understanding but also encourages student engagement and collaboration in the learning process.

Furthermore, the use of interactive digital media has also been shown to improve critical thinking skills and student engagement in learning, especially when combined with a problem-based or project-based approach (Purwaningsih et al., 2025). This explains why in this study, students demonstrated increased responsibility and active participation during the learning process. In terms of media development, this study's results align with other research showing that e-modules developed with a systematic, technology-based approach have high validity and effectiveness and can improve learning quality. Thus, the results of this study not only confirm previous findings but also extend them by adding a value dimension to learning.

In terms of implementation, this e-module has the potential for wider adoption. However, several challenges need to be addressed, including the readiness of the technological infrastructure, students' digital literacy, and lecturers' readiness to integrate prophetic values into learning. Furthermore, the continued use of this e-module also requires institutional support, including training, ongoing content development, and integration into the curriculum. Therefore, the implementation of this e-module depends not only on the quality of the product but also on the readiness of the overall learning system.

CONCLUSION

Overall, this study shows that e-modules designed using the OBE approach and infused with prophetic values are effective in improving students' understanding, ease of use, and the quality of materials delivered in statistics courses at FKIP Universitas Muhammadiyah Metro. The development of this e-module not only helps achieve OBE-based learning objectives but also helps instil moral and ethical values relevant to prophetic principles. In addition, the success in integrating prophetic values into e-modules underscores the importance of a comprehensive learning approach that does not focus solely on academic aspects but also on students' moral and spiritual development. Suggestions for further development include testing the OBE-based e-module developed in other study programs to assess its effectiveness across different courses, especially those involving quantitative materials. In addition, to make the e-module more engaging and easier for students to understand, it is recommended to include interactive features such as quizzes, online discussion forums, or explanatory videos to strengthen student involvement in the learning process.

ACKNOWLEDGEMENT

Deep gratitude to Universitas Muhammadiyah Metro and the Institute for Research and Community Service (LPPM) of Universitas Muhammadiyah Metro for their support and assistance throughout this research. This research would not have been carried out properly without the support of both institutions. We greatly appreciate the opportunity given to conduct this research

and hope that the results can provide significant benefits in the development of education at Universitas Muhammadiyah Metro, especially in the field of OBE-based statistics learning combined with prophetic values.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (44-56)
Online: http://journal.uny.ac.id/index.php/jitp

Toraja local wisdom e-comics with a STEM approach to improve mathematical concept understanding and problem-solving skills

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ARTICLE INFO

Article History
Received:
13 November 2025;
Revised:
5 March 2026;
Accepted:
31 March 2026;
Available online:
31 March 2026.

Keywords
E-comics;
Mathematical concept understanding;
Problem solving;
STEM; Toraja local wisdom

ABSTRACT

Mathematics learning is often perceived as difficult due to its abstract nature and the lack of contextual media that connect concepts to students' real-life experiences. However, Toraja culture contains various elements embedded with mathematical principles, such as symmetrical carving patterns, the geometric structure of Tongkonan, and traditional calculations in social practices. These cultural aspects can serve as meaningful visual and narrative contexts to support conceptual understanding. This study aims to develop a Toraja Local Wisdom E-Comic based on the STEM approach to enhance students' conceptual understanding and problem-solving skills in mathematics. The research employs the ADDIE model, consisting of analysis, design, and development stages. The e-comic is presented as an interactive digital medium integrating Toraja cultural stories with mathematical concepts and STEM-based explanations. Validation was conducted by material and media experts, while practicality testing involved students as users. Data were analysed using descriptive, quantitative, and qualitative methods. The results indicate high validity, with average scores of 4.72 for material aspects and 4.65 for media aspects. The practicality test yielded an average score of 4.66, indicating that the e-comic is easy to use, engaging, and effective in facilitating understanding through cultural context. Therefore, the e-comic is considered valid and practical, with strong potential to improve mathematics learning outcomes. Further research will examine its effectiveness in classroom implementation.

How to cite:
Lolang, E., & Pratama, M. P. (2026). Toraja local wisdom e-comics with a STEM approach to improve mathematical concept understanding and problem-solving skills . *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 44-56. https://doi.org/10.21831/jitp.v13i1.91355

INTRODUCTION

Mathematics is one of the disciplines that plays a fundamental role in developing students' logical, analytical, and systematic thinking skills. At various levels of education, mathematics is often a challenging subject due to its abstract nature and the need for strong conceptual understanding (Bennett et al., 2008; Kornia et al., 2022). Students often struggle to understand basic mathematical concepts such as geometry, relations, algebra, and problem-solving because the learning process remains procedural and lacks context. Many students memorise mathematical procedures without understanding the meanings of the concepts. As a result, problem-solving skills, which are an essential goal of mathematics learning, do not develop optimally (Sudadi et al., 2023).

These difficulties are exacerbated when learning focuses solely on verbal explanations, symbolic abstractions, and repetitive exercises (Widodo et al., 2025; Kurniasih et al., 2025). In fact, mathematics learning will be more meaningful if students can relate mathematical concepts to real-life phenomena that they are familiar with (Chen & Tsai, 2021; Gravett et al., 2021). The contextual teaching and learning perspective emphasises that abstract concepts must be brought into everyday situations so that students can build meaningful cognitive structures (Madekhan, 2020; Azmi & Ummah, 2021). In this context, the use of learning media that are close to local culture is a very promising approach for connecting mathematical concepts with students' everyday experiences (Aries, 2023).

Indonesia has extraordinary cultural diversity, and each region offers visual, symbolic, and mathematical representations that can serve as a learning context (Lubis et al., 2022; Yudistira et al., 2022). One culture rich in mathematical elements is the Toraja culture in South Sulawesi. Toraja is known for its rich traditions, carved symbols, geometric patterns, traditional calculations, and the architectural structure of Tongkonan, which has symmetry, proportions, and geometric shapes closely related to mathematical concepts (Embon, 2019; Tandira'pak, 2022; Ikramah et al., 2022; Pasoloran et al., 2023; Ratnawati, 2019). Toraja carvings, for example, contain symmetrical patterns, rotations, reflections, and translations, which are core elements of transformational geometry. Similarly, the structure of the Tongkonan roof includes certain proportions and ratios that can serve as a context for discussing concepts of comparison, measurement, and simple trigonometric calculations. However, the potential of Toraja culture as a means of learning mathematics has not been optimally utilised in modern learning media.

In today's era of digital transformation, learning media need to keep pace with developments in information technology in order to attract the interest of young people who are familiar with digital devices (Pakoglean et al., 2024; Sutardi, 2022; Tulungen et al., 2022). One form of digital media that is effective for conveying material visually and narratively is e-comics. E-comics enable the conveyance of mathematical concepts through stories, illustrations, dialogue, and attractive visualisations, thereby helping students gradually understand abstract concepts (Filjinan et al., 2022; Huda, 2021; Yudha et al., 2018). E-comics can improve students' scientific literacy and creative thinking skills because their visualisations are easy to understand. On the other hand, comics based on local culture have also been proven to strengthen identity, increase the relevance of learning, and build emotional connections between students and the material being studied (Cahyono et al., 2023; Huda, 2021; Wicaksana et al., 2020).

Although e-comics have been widely developed across various fields of learning, studies that integrate Toraja local wisdom with the STEM approach in the context of mathematics learning remain very limited. In fact, the STEM (Science, Technology, Engineering, Mathematics) approach is an integrated learning approach that helps students understand how mathematical concepts are used to solve real problems holistically (Prasetyo, 2017; Mulia, 2020). STEM encourages students to think across disciplines, use technology as a tool, and apply mathematical concepts in the engineering or problem-solving process. Thus, the integration of STEM and locally-based e-comics is a highly relevant combination for improving the quality of contextual, engaging, and meaningful mathematics learning (Angga et al., 2020; Kismawati et al., 2022).

Mathematical problem-solving skills are one of the key 21st-century competencies that students must master (Kornia et al., 2022; Sutrisno et al., 2020). According to Polya, problem-solving is a complex process that involves understanding problems, devising strategies, implementing them, and evaluating solutions. Conventional mathematics learning, which emphasises only problem-solving procedures, is unable to optimally develop these skills. STEM-based e-comics have great potential to develop problem-solving skills because they can present contextual, challenging, and realistic problem situations, thereby encouraging students to think critically and creatively in finding solutions (Hamimah et al., 2022; Samal et al., 2021). The stories and visuals presented in e-comics allow students to understand the problem's flow, visualise mathematical information, and independently explore the steps to solve it. Previous studies have shown that e-comics can improve engagement and conceptual understanding, while STEM-based learning enhances problem-solving skills. However, most of these studies use decontextualised

content without strong cultural integration. Conversely, research on local wisdom or ethnomathematics highlights the importance of cultural context but is generally limited to traditional or non-digital media. In addition, studies combining STEM and digital media often emphasise interdisciplinary learning but often overlook culture as a central component. As a result, the integration of culture, STEM, and digital media remains partial and fragmented. This study addresses this gap by integrating Toraja local wisdom, the STEM approach, and interactive e-comics into a unified learning design. Unlike previous research, local culture is positioned as the core foundation for constructing mathematical concepts and for problem-solving activities, rather than merely as a supplement. Therefore, the novelty of this research lies in its holistic integration of culture, technology, and STEM, offering both pedagogical innovation and a contribution to cultural preservation through digital learning media.

Furthermore, the use of local wisdom in learning media provides additional benefits, including strengthening students' character and cultural identity. Integration of local cultural values into learning can foster a sense of pride, deepen understanding of society's moral values, and enrich the learning experience (Irvan et al., 2017; Tadius & Salu, 2021). In the context of Toraja, values such as cooperation, precision in carving, and discipline in traditional rituals can serve as inspiration for applying the STEM approach. This contributes to students' character development while preserving Toraja cultural values in modern education. However, the reality on the ground shows that mathematical content is still rarely packaged in local cultural narratives, especially in interactive digital media. Most mathematical learning media are still textual, linear, and lack challenge. Students find it difficult to understand concepts due to a lack of visualisation and minimal real-world context. Therefore, the development of Toraja Local Wisdom E-Comics grounded in STEM is highly relevant for addressing these needs (Aprilia et al., 2023; Suryani et al., 2023). This medium not only combines cultural elements and visual storytelling but also includes step-by-step, systematic presentations of mathematical problem-solving.

This e-comic development research focuses on creating interactive media prototypes featuring illustrations of Toraja culture, context-based mathematical explanations, and STEM-based problem-solving activities. This development is very important as a learning innovation that can replace conventional media that is less appealing. By utilising digital platforms such as FlipHTML5 or illustration applications, e-comics can be presented in a responsive format, easily accessible via mobile devices or laptops, and equipped with interactive features that enhance user engagement. Furthermore, this research is part of efforts to decolonise the curriculum, in which local culture is not merely used as a supplement to learning but becomes the core context of mathematical knowledge. This aligns with the direction of the Merdeka Curriculum policy, which emphasises context-based learning, experiential learning, projects, and the integration of local culture across various subjects. Thus, the development of this e-comic is not only a media innovation but also a contribution to strengthening cultural identity and improving the quality of learning in higher education. Based on this description, this research is very important for filling the gap between the needs of modern mathematics learning and the rich mathematical potential of local culture.

The Toraja Local Wisdom E-Comic with a STEM Approach is expected to serve as a learning medium that improves students' understanding of mathematical concepts while developing their problem-solving skills through a visual, contextual, and interdisciplinary approach. To strengthen the state of the art, recent studies indicate that STEM-based digital learning media, particularly e-comics, have significant potential to enhance students' conceptual understanding and engagement. However, most existing studies focus on general contexts and rarely integrate local cultural wisdom as the core learning framework. Previous research has developed STEM-based e-comics or ethnomathematics-based learning separately, but few studies have combined local wisdom, STEM, and digital narrative media in a single integrated design. Therefore, this study offers a novel contribution by integrating Toraja local wisdom into STEM-based e-comics for mathematics learning. Unlike prior studies, this research positions local culture not merely as contextual support but as the main narrative foundation for constructing mathematical understanding. This approach contributes both pedagogically (innovative contextual learning

media) and culturally (preservation of local wisdom through digital education). Hence, this study fills the gap between culturally relevant pedagogy and technology-integrated STEM learning.

METHOD

This study utilised the Research and Development (R&D) method with the ADDIE model, comprising five main stages: Analysis, Design, Development, Implementation, and Evaluation. This model was chosen because it provides a systematic and appropriate framework for producing digital learning media products, such as e-comics, grounded in local wisdom and a STEM approach. In the year of this study, the main focus was on the first three stages, namely needs analysis, media design, and initial product development, along with feasibility testing. In contrast, the implementation and effectiveness evaluation stages will be carried out in the following year's study.

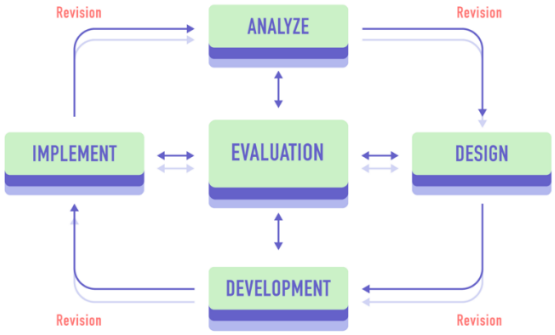

Figure 1. ADDIE Model

Analysis

The analysis stage was conducted to identify the needs of students and lecturers, as well as the relevant mathematics learning context. Data collection was carried out through needs questionnaires, preliminary interviews, and observations of ongoing learning patterns. An analysis of the mathematics material was also conducted to determine the appropriate concepts to include in the e-comics, such as geometry, patterns, and problem-solving. In addition, a study of Toraja culture was conducted to select cultural elements suitable for use as visual and narrative contexts, such as the geometric structure of Tongkonan, symmetrical carving patterns, and traditional activities that have mathematical connections. The results of this analysis form the basis for the design of contextual and meaningful media.

Design

The design stage involved compiling the storyline, initial storyboard sketches, e-comic page structure, and determining the visual design and illustration style. At this stage, the researchers also mapped out how STEM elements would be narratively integrated into the story. They designed a storyline that combined local cultural phenomena with mathematical problems the comic's characters had to solve. The design is created with consideration for readability, visual appeal, page proportions, and the integration of learning elements such as problem-solving exercises, brief concept explanations, and mathematical visualisations.

Development

The development stage is the process of producing a prototype version of the e-comic. The e-comic is developed in an interactive digital format using illustration software and a flipbook platform. Illustrations of Toraja culture are combined with mathematical concepts and narrative dialogue to guide students in understanding and thinking critically as they solve problems. After the initial prototype was completed, it was validated by experts, namely mathematics subject matter

experts and digital learning media experts. The validators assessed the suitability of the content, the accuracy of the concepts, the cultural appropriateness, the quality of the visual design, and the suitability of the media with STEM principles. The validation results were then used to revise the prototype. After revision, a practicality test was conducted with students using a questionnaire to assess ease of use, attractiveness, clarity of instructions, and the benefits of the media in mathematics learning.

Validity Test Assessment Scale (Subject Matter Experts and Media Experts)

The validity test involved two groups of experts: mathematics subject-matter experts and digital learning media experts. The purpose of the validity test was to ensure that the e-comics developed met the requirements of content appropriateness, conceptual accuracy, design quality, and cultural suitability, as reflected in the comics' narratives and illustrations. Subject matter experts assess the accuracy and completeness of mathematical concepts, the relevance of STEM integration, and the integration of Toraja local wisdom and mathematical learning objectives. The assessment also covers the logic of the storyline, the clarity of concept presentation, and the consistency of the material with the applicable learning outcomes. Meanwhile, media experts assess visual quality, layout, interactivity, page navigation, text readability, and the suitability of the e-comic format for use in digital learning. Aesthetic aspects and the harmonisation of local culture in illustration design are also important considerations in media assessment. Both groups of experts provide assessments on a five-point Likert scale, ranging from 1 (very poor) to 5 (very good). This scale is designed to quantify product quality, thereby facilitating the analysis and interpretation of results. The higher the validator's score, the higher the product's suitability and quality. The average validity score is then converted into specific categories, such as "very valid," "valid," "sufficiently valid," or "less valid." A product is declared suitable if the average score is in the valid or very valid category (≥ 3.41).

Table 1. Media Expert Validation Likert Scale

No.	Score	Assessment Categories
1	5	Highly Valid
2	4	Valid
3	3	Sufficiently Valid
4	2	Invalid
5	1	Highly Invalid

Practicality Test Assessment Scale (Users/Students)

In addition to being assessed by experts, e-comics are also tested for practicality through evaluations by end users, i.e., students. The practicality test aims to determine the extent to which the media is easy to use, easy to understand, visually appealing, and useful in assisting mathematics learning. The aspects assessed in the practicality test include the ease of operating the e-comic, the clarity of the instructions for use, the readability of the story and mathematical text, visual appeal, the clarity of the illustrations of Toraja culture, and the extent to which the media helps students understand concepts and solve mathematical problems. The assessment also covers students' perceptions of learning motivation and their comfort with using media on digital devices. The practicality instrument uses a five-point Likert scale, with categories ranging from 1 (not practical) to 5 (very practical). These score categories provide an overview of the practicality of the media from users' perspectives. The media is considered practical if the average score is ≥ 3.41, and very practical if the average score is≥ 4.21.

Table 2. Likert Scale of Practicality

No.	Score	Category
1	5	Very Practical
2	4	Practical
3	3	Quite Practical
4	2	Less Practical
5	1	Impractical

In this year of research, the study was limited to the development stage, including needs analysis, design, prototype creation, expert validation, and practicality testing. Large-scale implementation and testing of the media's effectiveness were not carried out at this stage. These stages will be the focus of next year's research, so that the work produced this year will be a prototype e-comic that has been declared valid and practical from the perspective of early users, but has not been empirically tested for its effectiveness in improving mathematical concept understanding and problem-solving skills. Thus, the implementation and evaluation stages will continue in the next phase of the research to obtain comprehensive evidence on the impact of using e-comics in mathematics learning.

RESULTS AND DISCUSSION

Results

This section presents the findings from the development of the Toraja Local Wisdom E-Comic using the STEM approach. The results are organised according to the ADDIE model, focusing on the Analysis, Design, and Development phases completed in this study. Each stage provides important insights into how the product was systematically developed, validated, and tested for practicality. The presentation of the results begins with the needs analysis, which explores the learning conditions, student difficulties, and the potential of integrating Toraja local wisdom into mathematics learning. This is followed by the design stage, which describes the development of the storyline, visual elements, and STEM integration within the e-comic. Furthermore, the development stage outlines the production of the e-comic prototype, including expert validation and user practicality testing.

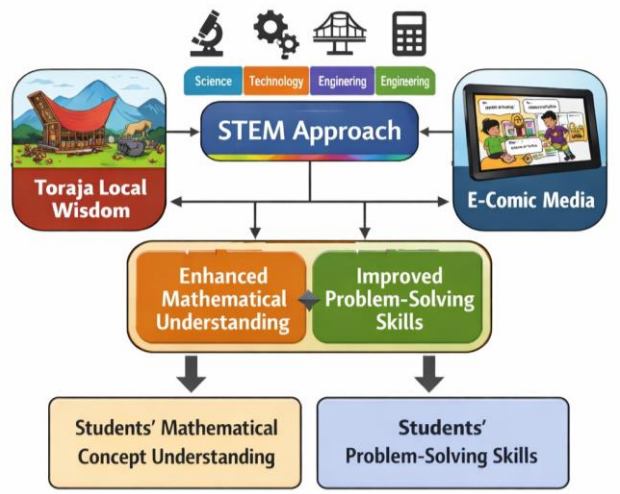

Figure 2. Conceptual Framework of the Study

Through this structured presentation, the results not only demonstrate the feasibility of the developed media but also provide a comprehensive understanding of how cultural context and STEM principles can be effectively integrated into digital learning media. These findings serve as the basis for further discussion of the relevance, strengths, and potential impact of the developed e-comic in improving students' understanding of mathematical concepts and problem-solving skills.

Requirements Analysis

The analysis stage was conducted through preliminary observations, interviews with lecturers teaching Basic Mathematics at Universitas Kristen Indonesia Toraja, and the distribution of questionnaires to 35 second-semester students. The purpose of this stage was to identify the need for innovative, contextual and engaging learning media. Key findings:

a. As many as 82.8% of students stated that they had difficulty understanding abstract mathematical concepts, particularly in relation to force, pressure and energy.

b. 74.3% of students mentioned that the learning media used were still conventional (PowerPoint and textbooks), making them less interesting.
c. 91.4% of respondents stated that media that incorporated local Toraja culture could increase their interest in learning.
d. Lecturers also emphasised the need for visual and narrative-based media, which could explain scientific concepts through real-life contexts.

In addition, an analysis of the Toraja local culture was conducted to determine relevant elements of local wisdom. As a result, three cultural contexts were selected for integration into the comic:

a. The structure of the Tongkonan as a representation of the concepts of force and balance.
b. The Rambu Solo' and Rambu Tuka' ceremonies to explain the principles of energy, force, and pressure.
c. The traditional Toraja rice field irrigation system to illustrate the concepts of fluid and hydrostatic pressure.

This stage establishes a strong conceptual foundation for media design through a contextual, meaningful STEM approach.

Design

During the design stage, the research team compiled the script and storyboard for the e-comic and designed the main characters. It determined the storyline that illustrates the application of mathematical concepts in the lives of the Toraja people. Design results:

a. The story script consists of five chapters, each covering a different mathematical topic within the context of Toraja culture.
b. The visual storyboard was developed using the ADDIE instructional design approach, integrating aspects of Science, Technology, Engineering, and Mathematics (STEM) into each chapter.
c. The dialogue between characters is designed to foster scientific thinking and problem-solving, not just entertaining narration.
d. The visual design uses a combination of 2D digital illustrations and light animated elements, adapted for an interactive flipbook format that can be accessed via laptop and smartphone.

Key components of e-comic design: (1) Opening page: introduction to Toraja cultural context; (2) Interactive storyline: presents mathematical problems in traditional life; (3) Interactive exercises (reflective quizzes): help students test their understanding of concepts; (4) STEM and culture summary: emphasises the connection between science and local wisdom. From the initial design test involving five students, positive responses were obtained, with average scores of 4.35 out of 5 for visual clarity and 4.22 out of 5 for narrative flow.

Development

The development stage produced a digital version of the e-comic (prototype 1) using the FlipHTML5 application.

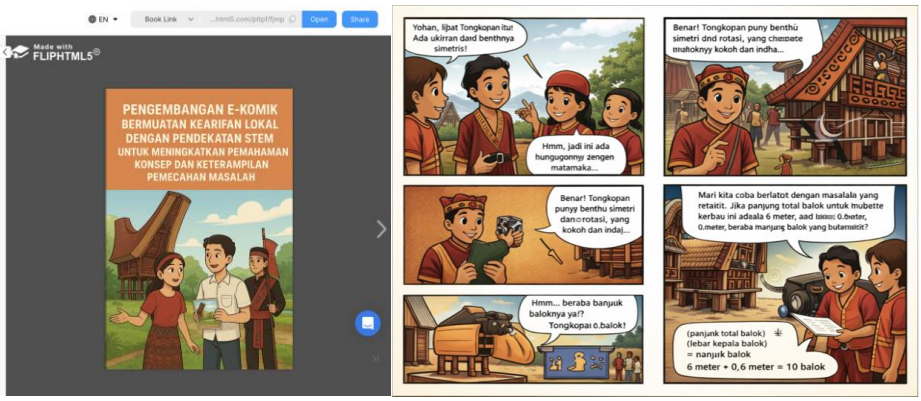

Figure 3. Flipbook-based E-Comics

This product comes with light animation and interactive page transitions. Audio narration in the cultural dialogue section. Interactive multiple-choice quiz-based exercises to test understanding of mathematical concepts.

Material Validity Test

Validation was carried out by two lecturers specialising in Mathematics Education and one STEM expert. The aspects assessed included content suitability, scientific concept accuracy, and cultural integration.

Table 3. Material Validity Test

No.	Assessment Aspects	Average	Category
1	The truth of mathematical concepts	4,80	Very Valid
2	Cultural context integration	4,75	Very Valid
3	STEM integration	4,70	Very Valid
4	Relevance to learning outcomes	4,60	Valid
5	Language comprehension and narration	4,65	Valid

Average material validity score: 4.70 (highly valid category). Validators' comments suggested adding a glossary of local terms to help students better understand the cultural context.

Media Validity Test

Media validity testing was conducted by two experts in educational technology and graphic design. The aspects assessed included visual appearance, interactivity, navigation, and audio-visual quality.

Table 4. Media Validity Test

No.	Assessment Aspects	Average	Category
1	Visual design and illustration	4.80	Very Valid
2	Interactivity and navigation	4.60	Valid
3	Consistency of appearance	4.75	Very Valid
4	Graphics and audio quality	4.50	Valid
5	Text readability	4.70	Very Valid

Average media validity score: 4.67 (highly valid category). The main suggestions are to increase the text size on mobile devices and slow down page transitions.

Media Practicality Test

The practicality test was conducted on 10 students of the Mathematics Study Programme at Universitas Kristen Indonesia Toraja through a user response questionnaire.

Table 5. Practicality Test

No.	Assessment Aspects	Average	Category
1	Ease of use	4.60	Very Practical
2	Appealing appearance	4.75	Very Practical
3	Clear instructions and navigation	4.55	Practical
4	Engagement in learning	4.70	Very Practical
5	Benefits for conceptual understanding	4.65	Very Practical

Average practicality score: 4.65 (very practical category). Students stated that e-comics helped them understand mathematical concepts more quickly because the storyline was directly related to phenomena around them. This medium has met the eligibility criteria for use in limited trials (implementation stage). In addition to serving as a learning medium, these e-comics also strengthen the preservation of Toraja local culture by integrating cultural values and symbols into scientific narratives.

Discussion

The results of the study indicate that the Toraja Local Wisdom E-Comic with a STEM Approach developed is highly valid and practical, as evidenced by expert and user assessments. These findings show that integrating local cultural visuals, the STEM approach, and mathematical content can produce high-quality learning media that is relevant to students' needs. This discussion elaborates on these results by linking them to theory, previous research, and the context of culture-based mathematics learning. First, the validity test results show that the e-comic received an average score of 4.72 from subject matter experts and 4.65 from media experts, indicating high validity. This means the mathematical concepts presented are accurate, systematic, and aligned with the learning outcomes. The integration of Toraja local wisdom is considered to support conceptual understanding by presenting concrete contexts relevant to students' lives. These findings reinforce the view that culture-based learning can clarify abstract concepts and help students construct meaningful cognitive structures. The use of Toraja cultural elements, such as symmetrical carving patterns, the geometric structure of Tongkonan, and calculation-based traditional activities, proved effective as a bridge to understanding abstract mathematical concepts (Sihombing et al., 2022; Syafe'i & Effendi, 2020). Secondly, from a STEM perspective, e-comics are considered to have consistently integrated elements of Science, Technology, Engineering, and Mathematics into their narratives (Amicis et al., 2019). This is evident in how mathematical problems are linked to cultural phenomena and solved through scientific thinking, simple technological analysis, and problem-based engineering approaches. These findings align with Sunismi (2015), who states that STEM-based media can facilitate learners' understanding of concepts through authentic, contextual problem-solving. Thus, e-comics not only present information but also offer interdisciplinary learning experiences that stimulate higher-order thinking skills.

Third, the practicality test conducted by students yielded an average score of 4.66, indicating that e-comics are very easy to use, interesting, and useful for learning. Students stated that the presentation of mathematical material became easier to understand when it was accompanied by visual illustrations, stories, and problems familiar to their culture. This reinforces the research of Cahyono et al., (2023), which found that comic media can improve conceptual understanding through narratives that reduce cognitive load and help learners build better mental representations. The visual appeal and interactivity of e-comics have also been shown to increase student motivation and interest in learning, in line with Keller's ARCS theory, which states that attention and relevance are key aspects of effective learning design.

Fourth, this study's results also show that integrating local wisdom into learning media positively strengthens students' cultural identity. For example, depictions of the Tongkonan structure, carving patterns, and authentic Toraja social contexts enrich the learning experience and evoke an emotional connection to the material. These findings are consistent with studies by Situru & Tulak (2022) and Tadius & Salu (2021), which show that local wisdom-based learning not only improves academic competence but also fosters cultural pride and character values. In other words, e-comics serve not only as a means of conveying mathematical concepts but also as a medium for cultural preservation. Furthermore, this study's results show that e-comics have the potential to improve mathematical problem-solving skills. This can be seen in the story structure, which invites students to face real-life, culturally based problems, analyse information, choose solution strategies, and draw conclusions. This aligns with Polya's problem-solving framework, which emphasises the need to present contextual, challenging problems to train critical thinking skills. Although effectiveness testing has not been conducted at this stage, this potential has been evident from students' positive responses during the practical testing.

However, this study has limitations: it reached only the development stage and did not include empirical implementation and effectiveness testing. Therefore, the results obtained are still limited to content validity and media practicality. The next stage must be carried out to determine the extent to which e-comics can significantly improve students' understanding of mathematical concepts and problem-solving skills. Overall, the study's results indicate that Toraja Local Wisdom E-Comics with a STEM Approach are a feasible, practical, and promising learning medium for mathematics education. This medium not only presents concepts visually and narratively, but also

provides a contextual, interesting, and meaningful learning experience. These findings make an important contribution to the development of culture-based and STEM learning media and open the door to further research to test their effectiveness in broader learning contexts.

CONCLUSION

This development research produced a Toraja Local Wisdom E-Comic with a STEM Approach, intended as a mathematics learning medium to help improve students' conceptual understanding and problem-solving skills. Based on the entire series of processes in the development stage, it can be concluded that the developed medium meets the criteria of validity and practicality, making it suitable for use in the implementation stage and for effectiveness testing in subsequent research. The validity test results from subject matter experts and media experts indicate that the e-comic received an average score in the highly valid category. This confirms that the mathematical content presented is accurate, logical, and consistent with the learning outcomes; the integration of STEM elements is structured and relevant; and the representation of Toraja culture is appropriately conveyed and supports conceptual understanding. The visual design, navigation, readability, and interactivity of the media were also rated as very good, making it attractive and easy for users to understand the information.

Practicality tests involving student users showed that the e-comic falls into the highly practical category. Students assessed that the e-comic is easy to use, visually appealing, clear in its presentation of mathematical concepts, and provides a real-world context that makes it easier for them to understand mathematical problems. This media is also considered capable of increasing learning motivation and providing a more enjoyable learning experience compared to conventional methods. The integration of Toraja local wisdom into e-comics has proven to provide significant added value. Cultural contexts such as traditional carving patterns, the geometric structure of Tongkonan, and traditional activities help students connect mathematical concepts to real phenomena close to their lives.

This strengthens the relevance of learning while preserving local cultural values through modern and creative educational media. Although this study has not yet reached the effectiveness testing stage, findings from the development stage indicate strong potential for e-comics to improve understanding of mathematical concepts and problem-solving skills. Therefore, further research is needed to conduct implementation tests in larger classrooms using experimental designs to obtain empirical evidence on the influence of media on student learning outcomes. Overall, this research makes an important contribution to the innovation of local culture-based and STEM learning media. The e-comics developed not only meet the quality standards for learning media, but also offer a contextual, engaging, and meaningful approach to improving the quality of mathematics learning in higher education and schools.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (57-69)
Online: http://journal.uny.ac.id/index.php/jitp

Enhancing student academic services through AI-driven virtual assistants using the RAG method at Universitas Terbuka

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ARTICLE INFO

Article History
Received:
28 February 2025;
Revised:
10 June 2025;
Accepted:
10 June 2025;
Available online:
31 March 2026.

Keywords
Chatbot; Large language model; RAG; Virtual assistant

ABSTRACT

The Indonesian Open University currently operates an information service called Hallo UT, which mainly provides academic and administrative information. To improve this service, this study develops a virtual assistant chatbot capable of delivering autonomous 24-hour customer support using a Retrieval-Augmented Generation (RAG) approach. RAG combines information retrieval techniques with large language model capabilities to generate accurate and contextually relevant responses. Data were collected from academic manuals containing frequently asked questions and questionnaires distributed to 76 students. The chatbot was evaluated based on accuracy, response time, and user satisfaction. Results show that the system achieved an average accuracy rate of 92% with an average response time of 5 seconds. In addition, 62% of students responded positively to the chatbot's functionality. These findings demonstrate the chatbot's potential to improve student engagement, reduce administrative workload, and enhance the overall learning experience. Future research should involve larger samples, multilingual support, and broader system integration.

How to cite:
Susilo, A., et al., (2026). Enhancing student academic services through AI-driven virtual assistants using the RAG method at Universitas Terbuka. *Jurnal Inovasi Teknologi Pendidikan*, *13*(1), 57-69. https://doi.org/10.21831/jitp.v13i1.83632

INTRODUCTION

In the ever-evolving landscape of higher education, universities and colleges continuously seek new ways to enhance academic services and student support. One promising approach is the use of AI-powered virtual assistants, which can provide personalised, adaptive support to students throughout their learning process (Berkat, 2024).

AI has had a significant impact on e-learning, offering viable solutions to address the limitations of conventional e-learning approaches. AI-powered digital assistants can tailor learning by adjusting content, pacing, and feedback according to the specific needs of each student (Kashive et al., 2021). Moreover, adaptive assessment, another application of AI in e-learning, can track student progress and provide targeted feedback to support learning (Rasheed et al., 2023). Advanced implementations, such as smart tutoring systems, offer personalised guidance and support, improving both learning outcomes and student engagement (Castro et al., 2024).

As Indonesia's leading distance learning institution, Universitas Terbuka (UT) continues to improve the quality of its academic services. One of the innovative efforts underway is the development of an AI-based virtual assistant to support real-time interaction and information needs. This study specifically examines the application of the retrieval-augmented generation (RAG) model to develop an intelligent chatbot for UT. Supported by RAG, this chatbot is designed to handle a wide range of student inquiries, from course-specific information to general academic support, to increase efficiency and accessibility in a distance learning environment (Vázquez et al., 2021).

A chatbot is an AI-powered conversational service that simulates human interaction. This technology can understand and process user requests, delivering quick, relevant responses (Dongbo et al., 2023). It operates by scanning keywords from user input and matching them to predefined patterns or keyword sets, generating automatic responses based on the best match (Dongbo et al., 2023).

To date, Universitas Terbuka has not implemented a chatbot service. The university lacks a 24-hour interactive communication platform. Customer service at UT's Centre for Information and Communication Technology (PTIK) is not available around the clock, even though students often need information outside regular working hours. Chatbot technology presents a promising solution to this issue, offering the potential to serve as a virtual assistant, replacing conventional customer service by providing timely information and communication support (Santos et al., 2022).

Previous studies have highlighted the potential of chatbots in education. For instance, a study explored the use of chatbots to respond to administrative queries at a private university (Ramakrishnan et al., 2024), while another study investigated user satisfaction with mobile-based university chatbots (Nasa et al., 2023). Additionally, research emphasised how chatbot systems can enhance student learning experiences through responsive two-way interaction (Baha et al., 2024). Another study found that implementing chatbots in higher education institutions could reduce the workload of information service staff by up to 40% (Popescu et al., 2023). However, most of these studies focus on traditional or rule-based chatbot systems, with limited attention to the context of large-scale distance education, such as that of Universitas Terbuka. This presents a research gap: how to design and implement an AI-powered chatbot using a modern RAG approach to support real-time academic services in distance learning settings.

Furthermore, implementing AI in academic services is not without challenges. One major issue is the availability and quality of internal data needed to train AI models that can accurately respond to student queries (Su & Yang 2023). Based on internal observations, approximately 40% of student inquiries to customer service are repetitive and administrative, such as exam schedules, re-registration procedures, or assignment submission guidelines. Yet, they are not systematically documented in a database that an AI system could readily utilise.

This study aims to implement a retrieval augmented generation-based chatbot as a virtual assistant at Universitas Terbuka to improve the effectiveness of real-time academic information services for students. The key contribution of this research is the development of an AI-based chatbot implementation model suited to distance education contexts, along with a comprehensive analysis of the technical and non-technical challenges encountered during its development. The findings are expected to serve as a reference for other higher education institutions seeking to adopt AI technologies to deliver more responsive and inclusive academic services.

METHOD

The development of the AI-based virtual assistant at the Open University of Indonesia followed a multi-step process: (1) Knowledge base curation, the university's academic and administrative data, including course materials, syllabi, and student support resources, were compiled to create a comprehensive knowledge base for the virtual assistant (Sugianto et al., 2021). (2) Language processing, a natural language processing module was developed to understand and interpret student queries, leveraging techniques such as intent recognition and entity extraction (Sajja et al., 2023). (3) Natural language processing, a natural language processing module was developed to understand and interpret student queries, enabling the virtual assistant to provide relevant and personalised responses (Tu et al., 2023). (4) Retrieval augmented generation, the retrieval augmented

generation method was implemented to generate contextually appropriate responses by combining language model-based generation with information retrieval from the knowledge base (Jiang et al., 2023). (5) Adaptive assessment, the virtual assistant's capabilities were extended to include adaptive assessment, allowing the system to evaluate student progress and provide targeted feedback and support continuously (Kadaruddin, 2023). (6) Integration with learning management system, the AI-based virtual assistant was seamlessly integrated with the university's learning management system, providing students with a unified and accessible academic support platform (Latif et al., 2024; Lee et al., 2024).

In addition, some steps have been taken to implement Retrieval-Augmented Generation (RAG) in this research: (1) Data collection, gathering relevant documents, articles, FAQs, and website knowledge bases. Focus on comprehensiveness, ensuring the data covers a wide range of topics a chatbot might encounter. (2). Data transformation, implement an Extract-Transform-Load (ETL) process to combine data from various sources into a single, unified format. This step involves cleaning, structuring, and standardising the data for consistency. (3) Data vectorisation, load the preprocessed data from step 2 into ChromaDB, a vector database. ChromaDB stores data in a format that enables efficient similarity-based searching. This involves creating vector representations of the data points, enabling faster retrieval of relevant information during user queries. (4) Query and retrieval, this stage combines retrieval and generation, the core of RAG. Retrieval: When a user asks a question, the system formulates a query based on the user's input. This query is then used to search ChromaDB for the most relevant documents. The search leverages the vector representations created earlier to find documents with high semantic similarity to the user's query. (5) Augmentation: the retrieved documents from ChromaDB are then combined with the original user query. This creates a richer context, providing additional information for the large language model. Essentially, we provide the LLM with both the user's question and related information from the knowledge base. (6) Response generation with LLM, the augmented query, containing both the user input and relevant retrieved documents, is sent to OpenAI's large language model (LLM). The LLM leverages its capabilities and the provided context to generate a response. By using the retrieved information, the LLM can produce more informative and accurate answers that are grounded in factual knowledge. This is a simplified overview of implementing RAG. There are additional considerations, such as choosing the appropriate data sources, fine-tuning the retrieval process, and potentially using different vectorisation techniques or LLMs. The implementation of Retrieval-Augmented Generation (RAG) in this study is shown in Figure 1 below.

Figure 1. AI Virtual Assistant Development Process

Testing the Accuracy Rate of Chatbot

The testing accuracy rate can be calculated using the accuracy formula as presented in Formula 1 below.

$$Accuracy = \frac{Total\ Right\ Answers}{Total\ Questions} 100\% \quad (1)$$

User-Acceptance Test

A User Acceptance Test is a test conducted to verify that the software built to meet existing needs is acceptable. The purpose of UAT is to identify the determinants of general computer acceptance that explain user behaviour across various computing technologies. In this study, the UAT was conducted with 76 student respondents from Universitas Terbuka (UT) to assess the effectiveness and acceptance of the AI-based virtual assistant system. The Questionnaire Instrument is shown in Table 1.

Table 1. Questionnaire Instrument

No.	Questions
1	Do you agree that the chatbot's response time is fast enough?
2	Do you agree that the responses provided by the chatbot are relevant to the questions you asked?
3	Do you agree that the chatbot introduces itself well enough for users to understand how to use it?
4	Do you agree that the chatbot functions properly?
5	Do you agree? How does the chatbot help you obtain academic-related information?
6	Do you agree that this chatbot makes it easier and faster for you to obtain information related to academic and administrative services at Universitas Terbuka?
7	Do you agree that the chatbot can serve as your primary virtual assistant for obtaining academic and administrative information at Universitas Terbuka?
8	Do you agree that the chatbot helps you get information related to academic and administrative matters?

RESULTS AND DISCUSSION

Results

The retrieval-augmented generation method has proven effective at generating contextually appropriate responses, drawing on the knowledge base to provide comprehensive and personalised support to students.

The virtual assistant has responded to many student queries with high accuracy and relevance, as evidenced by positive student feedback and improved satisfaction (Chheang et al., 2024). The adaptive assessment capabilities of the virtual assistant have also enabled the university to continuously monitor student progress and provide targeted support, thereby improving learning outcomes.

The retrieval-augmented generation method has enabled the virtual assistant to provide comprehensive, contextually appropriate responses, drawing on the rich knowledge base curated by the university.

Chatbot System Architecture

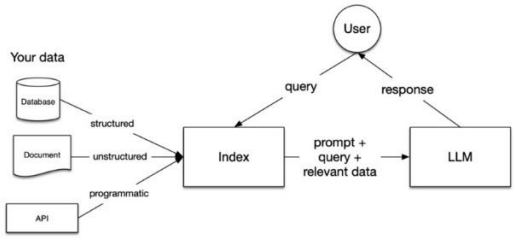

Figure 2. Chatbot System Architecture

is the architecture of the chatbot system. At this stage, text preprocessing is performed, including word weighting, document similarity calculation, and ranking by the highest weight value. When the user sends a message (query), the system processes the data by going through the text preprocessing stage, then calculates the data using the TF-IDF and VSM methods, and computes similarity using cosine similarity.

There are three main approaches to AI technology, namely fine-tuning, embedding, and Retrieval-Augmented Generation (RAG). Fine-tuning in AI involves adjusting pre-trained models to specific tasks, and slight variations in the fine-tuning process can significantly impact performance (Goyal et al., 2023; Zhang & Hu, 2021). Embedding refers to representing data in a lower-dimensional space, enhancing semantic similarity tasks without fine-tuning, as seen in music similarity research (Zhang et al., 2021). On the other hand, the Retrieval Augment Generation (RAG) approach focuses on end-to-end fine-tuning of the RAG architecture, surpassing the original model's performance in question answering tasks (Siriwardhana et al, 2021). While fine-tuning emphasises task-specific adjustments, embedding techniques aim to improve model performance without extensive retraining, and RAG highlights the benefits of end-to-end fine-tuning for specific architectures, showcasing the diverse strategies in AI technology. The AI Chatbot Based on the RAG Method as a Virtual Assistant is shown in Figure 3 below.

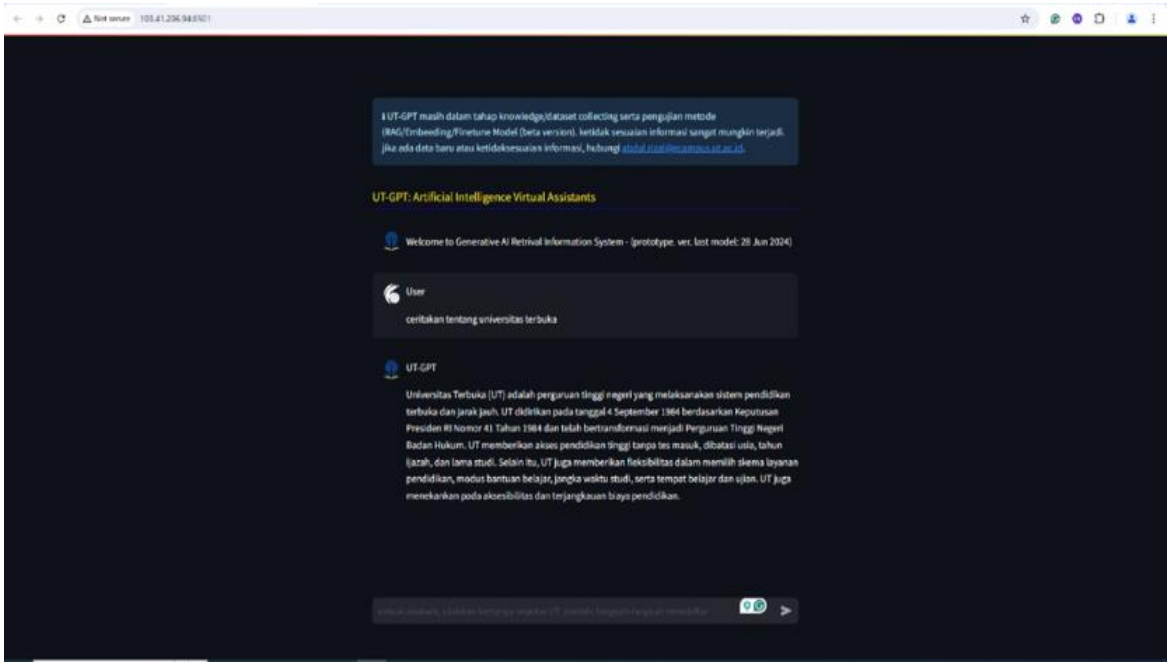

Figure 3. Chatbot AI-Based on RAG Method as a Virtual Assistant in UT

Testing Accuracy Rate

Testing Accuracy Rate is conducted using a dataset of 50 questions. Based on the test results, the system correctly answered 46 out of 50 questions, achieving an accuracy of 92%. These results indicate that the chatbot system has a relatively high level of accuracy in classifying and responding to user queries. However, several obstacles contribute to the remaining inaccuracies. One of the main issues is the presence of essential words across multiple sentence classes, which makes it difficult for the system to classify questions correctly. In addition, the use of non-standard Indonesian abbreviations, such as “mk” (mata kuliah/course) and “PS” (Program Studi/department), cannot be properly recognised by the system. Furthermore, informal and non-standard words such as “tak” (*tidak*/no) and “y” (*ya*/yes) are not processed effectively after tokenisation. These limitations reduce the system’s ability to achieve maximum accuracy in question classification.

User-Acceptance Test

Testing the chatbot application on 76 students. Testing respondents in four categories using chatbots, including ability, consistency, responsibility, and performance. Based on a questionnaire distributed to users, the chatbot was found to work well.

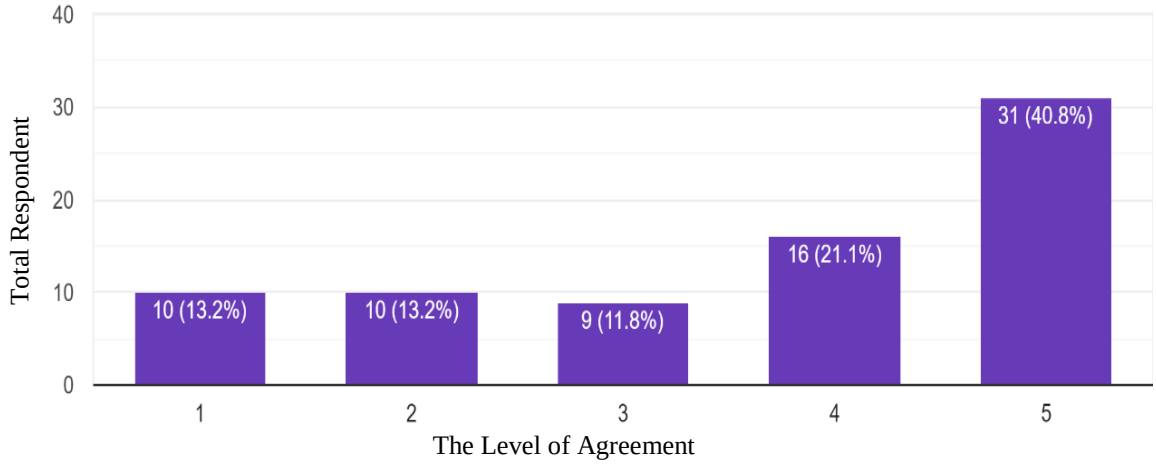

Figure 4. User Opinion on Chatbot Performance

Notes:

a. Strongly Disagree: Indicates the lowest level of agreement or strongest negative perception.
b. Disagree: Reflects disagreement with the statement but with less intensity than "Strongly Disagree".
c. Neutral: Represents the midpoint, indicating neither agreement nor disagreement, or ambivalence.
d. Agree: Implies agreement with the statement, though less intense than "Strongly Agree".
e. Strongly Agree: Represents the highest level of agreement or strongest positive perception.

Users agree that the chatbot can be a top priority as a virtual assistant to get information about Open University academics and administration.

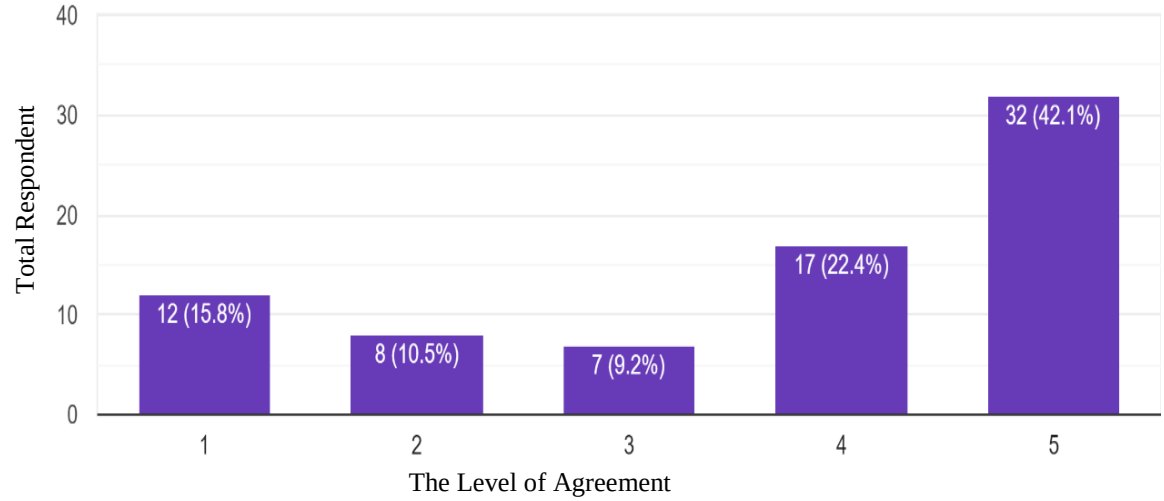

Figure 5. User Opinion on Chatbot as a Virtual Assistant

From these data, in Figures 4 and 5, it is evident that more than 60% of users state that using chatbot technology applications is better in terms of ability, consistency, responsiveness, and performance.

Discussion

Finetuning enhances AI model performance by adapting the weights of specific layers or groups of layers in pre-trained models to tackle domain-specific tasks effectively (Barakat & Huang, 2023). Traditional methods that focus on task-specific classifier weights or re-optimising all layers may lead to overfitting with limited data or fail to address the mismatch between pre-trained models and new-task data (Barakat & Huang, 2023). To address these challenges, novel block-wise optimisation mechanisms have been proposed, allowing for the adaptation of groups of layers in pre-trained models through various strategies like layer-wise adaptation, joint adaptation of top-ranked layers, block-based segmentation, and sliding window grouping, resulting in improved performance compared to baseline methods and layer-wise approaches (Barakat & Huang, 2023). Additionally, reinforcement learning-based finetuning methods have shown promise for enhancing AI systems' understanding of document images, especially in scenarios with limited training data, by jointly optimising combined reward functions alongside traditional losses (Nguyen et al., 2022).

Recent embedding techniques play a crucial role in enhancing AI model accuracy by optimising computation, reducing computational costs, and improving generalisation. Techniques such as network pruning, low-precision quantisation, and dynamic inference help compress models, thereby minimising computational and storage intensity (Liu, 2021). Additionally, approaches that replace data augmentation in the raw input space with an approximate augmentation in the embedding space significantly reduce computational cost while maintaining model accuracy (Abrishami et al., 2020). Moreover, using specific embedding strategies, such as GraNet layers in Graph Neural Networks, enables neighbourhood aggregation and the inheritance of weights from pre-trained models, leading to improved accuracy compared to traditional methods (Purchase et al., 2022). Furthermore, supervised document embedding designed for hierarchical text categorisation, trained on both words and labels, enhances embedding vectors by leveraging class hierarchy information, resulting in superior performance in text categorisation tasks (Saetia & Vateekul, 2018).

Recent advancements in embedding techniques have significantly impacted AI model performance. Techniques such as network pruning, low-precision quantisation, and dynamic inference have been proposed to compress models, reducing computational and storage requirements (Liu, 2021). Additionally, approaches such as transferring data augmentation from the raw input space to the embedding space have been introduced to decrease computational costs while maintaining model accuracy (Abrishami et al., 2020). Furthermore, optimising the deployment of embeddings using frameworks such as Hetero-Rec for recommendation models has shown substantial improvements in reducing inference latency by caching frequently accessed embeddings in faster memory (Mahajan et al., 2022). Tools like Emblaze have been developed to aid in comparing embedding spaces, enabling model builders to choose optimal representations and identify flaws for improved model performance (Sivaraman et al., 2022). These advancements enhance the efficiency and effectiveness of AI models.

Retrieval Augment Generation (RAG) is a cutting-edge technique in Open-Domain Question Answering (ODQA) that combines a retriever and a generator to enhance AI model accuracy. RAG has traditionally been trained on a Wikipedia-based knowledge base, limiting its adaptability to specialised domains such as healthcare and news (Siriwardhana et al., 2023). RAG-end2end, an extension of RAG, enables joint training of the retriever and generator components, facilitating domain adaptation by updating all knowledge base components during training and injecting domain-specific knowledge through an auxiliary training signal (Siriwardhana et al., 2023). Additionally, RAG has been successfully applied in automating radiology report writing, leveraging multimodal embeddings for retrieval and generative models for report generation, resulting in improved clinical metrics and the ability to tailor report content to specific clinical settings (Ranjit et al., 2023).

The rollout of AI-powered virtual assistants in higher education, such as those at the Open University of Indonesia, has had a significant impact on student academic services. These tools help in many ways. They provide quick, correct answers to student questions using the retrieval-augmented generation method. They also boost learning outcomes through adaptive assessment, which helps spot and address learning gaps. Linking the virtual assistant with the university's learning management system also made a single, easy-to-use platform for students who need academic help

(Sajja et al. 2023). Using the AI-powered virtual assistant at the Open University of Indonesia has shown clear gains in student academic services (Muhammad & Sudianto, 2023). The virtual assistant can answer many student questions, from course-related queries to general academic help, with high accuracy and relevance (Rios et al., 2023).

The retrieval-augmented generation method has been shown to produce responses that fit the context. It leverages the extensive information in the knowledge base to provide thorough, personalised help to students (Abu & Alotaibi, 2024). The virtual assistant has answered many different student questions, and students have given good feedback and are happier with the service (Chheang et al., 2024). The virtual assistant can also adapt its assessments. This allows the university to track how students are doing and provide help when they need it. As a result, students are learning better (Dogan et al., 2023).

The virtual assistant uses a method called retrieval augmented generation. This helps it provide full and fitting answers by drawing on the university's extensive body of knowledge (Wang et al., 2023). The virtual assistant's integration with the university's learning management system has created an easy-to-use, accessible academic support platform for students. This has boosted the impact of the AI-powered solution (Sajja et al., 2023). The AI-based virtual assistant rollout has succeeded, but the university still faces ongoing issues and considerations (Hajipour et al., 2023). These include ensuring data remains private and secure, reducing bias in algorithms, and continually improving the virtual assistant through machine learning and user feedback (Rios et al., 2023).

The retrieval-augmented generation method enhances the virtual assistant's ability to provide students with quick, correct answers to questions across many academic topics, from course-specific questions to general academic help (Sajja et al., 2023). The retrieval-augmented generation method combines the strengths of large language models with a vast knowledge base. This allows the virtual assistant to access and use information from various sources, such as course materials, syllabi, and student support resources (Gill et al., 2024).

When a student asks a question, the virtual assistant first uses natural language processing to understand the student's meaning and identify keywords (Hajipour et al., 2023). Then, it uses the retrieval-augmented generation method to search its knowledge base for the most accurate and up-to-date information (Zhang et al., 2024). It produces a full-fitting answer by combining its ability to generate language with the information it found (Walker et al., 2023). This method enables the virtual assistant to address many school-related issues, from specific questions about class material to general inquiries about school rules or help services, ensuring students receive quick, accurate information (Chheang et al., 2024).

The virtual assistant's ability to adapt its assessments has also shown its worth, enabling the university to identify learning gaps and offer targeted support to students, thereby improving learning outcomes (Dogan et al., 2023). Also, combining the AI-based virtual assistant with the university's learning management system has created an easy-to-use platform for students to access academic help, thereby improving their overall learning experience (Sajja et al., 2023). Putting the AI-based virtual assistant into action hasn't been smooth sailing. The team had to tackle some tricky issues. They took a hard look at ethical concerns, such as keeping people's data safe and ensuring the system treats everyone equally (TonbuloĞLu, 2023). Moreover, chatbots' ability to understand the variety of informal language, slang, and idiomatic expressions used by students in daily interactions is limited (Shams et al., 2024). In the increasingly diverse context of higher education, students not only use formal language when communicating but also mix technical terms, everyday language, and even popular social media abbreviations. When chatbots fail to understand expressions such as "tight credit hours", "sudden academic leave", or "grades not yet input", the user experience can be disrupted, and trust in the technology may decline. Future chatbot development should integrate natural language processing models that are more adaptive to non-standard and context-specific language (Suryanto et al., 2023). Approaches such as continual learning and contextual fine-tuning based on real student conversational data can be employed to broaden the chatbot's understanding scope. Additionally, integration with corpora of informal student conversations or campus social media could be a strategic step to enrich the chatbot's semantic comprehension (Lin et al., 2025). By comparison, a study by Belda & Calvo (2022) shows that chatbots designed for informal educational settings and online communities perform better when trained using datasets of representative

informal language. Therefore, in the future, chatbot design in campus environments should consider the linguistic and sociocultural aspects of students as primary users, ensuring that this technology is not only technically intelligent but also contextually relevant.

The launch of the AI virtual assistant at Universitas Terbuka Indonesia has shown promising results. The assistant can answer various student questions with high accuracy and relevance. The AI system architecture consists of a natural language processing (NLP) unit, an information retrieval unit, and an answer generation unit. This study's findings have significant potential to influence the design, implementation, and evaluation of AI-based Virtual Teaching Assistants in higher education. These findings could drive the creation of innovative learning tools to improve learning outcomes, student engagement, and satisfaction (Sajja et al., 2024). Moreover, more than 60% of users state that chatbot applications are superior in terms of ability, consistency, responsiveness, and performance compared to traditional service methods. This aligns with the findings of (Seraquive et al., 2024), which show that personalised and contextual chatbots can significantly enhance user satisfaction. The study by Seraquive et al., (2024) further supports this claim, where users felt that the interaction experience with chatbots was more consistent and responsive, especially in the context of academic and administrative support. These findings confirm the great potential of chatbot technology to improve the efficiency of higher education services.

CONCLUSION

The Open University of Indonesia's case study on using an AI virtual assistant shows how these smart systems can boost student academic services. The virtual assistant uses a method called retrieval-augmented generation to provide personalised, relevant answers. Its adaptive assessment features have helped students learn better. This research could shape how colleges design, roll out, and check AI-powered Virtual Teaching Assistants. It paves the way for new learning tools that can boost student learning, involvement, and happiness. We still need to study the long-term effects of AI virtual assistants on students' academic performance. We also need to consider the ethical implications of using this tech in education. For future research, it is recommended to expand the sample size and the diversity of respondents to gain more generalizable insights, incorporate multilingual support to accommodate a broader student population, and explore integrating the chatbot with other university systems to provide a more comprehensive academic service platform.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (70-81)
Online: http://journal.uny.ac.id/index.php/jitp

Evaluating the GET electrical technology syllabus for transition into FET specialisations in Gauteng Technical Schools

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ARTICLE INFO

Article History
Received:
22 October 2025;
Revised:
20 February 2026;
Accepted:
23 March 2026;
Available online:
31 March 2026.

Keywords
Curriculum; Electrical technology; FET phase; GET phase; Vocational education

ABSTRACT

This study examined the General Education and Training (GET) syllabus of Electrical Technology to determine its effectiveness in preparing learners for progression into Further Education and Training (FET) specialisations in Gauteng technical schools. The problem this research addresses is the persistent misalignment between the foundational competencies developed in the GET phase and the advanced technical expectations of the FET phase, leaving learners underprepared for specialisation. The purpose of the study was to explore how the GET curriculum supports or fails to support smooth curriculum transition in Electrical Technology. A qualitative case study design was employed, using document analysis and semi-structured interviews with eleven experienced teachers in Gauteng Province, South Africa. The findings revealed that the GET curriculum is mostly theoretical, with limited practical scaffolding and weak sequencing of advanced topics such as Three-phase motors and Transformers. Teachers noted repeatedly re-teaching basic concepts at the FET level, which created time pressures and contributed to learner frustration. The study concludes that improving vertical curriculum alignment through stronger practical integration and clearer teacher support mechanisms can enhance learner readiness, curriculum coherence and the overall quality of Vocational Education (VOC) in South Africa.

How to cite:
Dayi, N., Mtsali, T. I., & Sephokgole, R. D. (2026). Evaluating the GET electrical technology syllabus for transition into FET specializations in Gauteng Technical Schools. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 70-81. https://doi.org/10.21831/jitp.v13i1.90695

INTRODUCTION

The transition from General Education and Training (GET) to Further Education and Training (FET) in South Africa's technical schools represents a critical juncture in a learner's educational pathway. Within the subject of Electrical Technology, this transition covers Grades 8-9 through Grades 10-12, where learners progress from general foundational exposure to specialised areas such as Digital Systems, Electronics, and Electrical Power Systems (Andreassen & Kjelaas, 2025). The GET phase is intended to equip learners with both theoretical grounding and fundamental practical awareness (Elliott & Higgins, 2023). However, evidence indicates that many learners enter the FET phase without the depth or coherence to engage effectively with advanced content, thereby weakening their preparation for both higher education and industrial application (Carlsson & Willermark, 2025). This challenge points to a broader and persistent concern. The GET curriculum

fails to provide a strong conceptual and practical foundation for the demands of specialisation, leaving learners unprepared for the FET phase of Electrical Technology specialisations.

In the South African context, this gap between foundational preparation and advanced technical learning has significant implications for employability, skills development and the strength of vocational pathways in South Africa and globally. Emphasises that Technical Education plays a pivotal role in addressing the dual challenges of youth unemployment and the shortage of skilled artisans (Yeboah, 2024). Nevertheless, many learners arrive in FET classrooms ill-equipped to meet curriculum expectations due to misalignment between the GET and FET syllabi and inconsistent teaching practices. For international readers, it is important to note that South African learners can enter vocational pathways as early as lower secondary school (Ndimbira, 2024), unlike many European systems where Vocational Education (VOC) typically begins at upper-secondary level. Consequently, weaknesses within the GET phase have direct implications for both school-to-work transitions and progression into higher-level vocational studies (Marczuk, 2021).

This raises the central concern of the study: whether the GET syllabus equips learners with sufficient knowledge and practical competencies to meet the academic and technical demands of the FET phase. Curriculum coherence is widely acknowledged as a cornerstone of effective vocational education. International studies underline that alignment between foundational and advanced stages enhances learner progression, confidence, and employability (Bolton, 2022; Young & Hordern, 2022). In the South African context, similar concerns have been identified in subjects such as Mathematics, where discrepancies between curriculum policy and assessment practices hindered quality learning (Bertram et al., 2021). These findings suggest that Electrical Technology may face parallel challenges, as the subject's technical nature requires systematic progression and applied understanding (Gumede, 2023). Without a coherent bridge from GET to FET, learners risk developing fragmented conceptual knowledge that limits their capacity to handle complex electrical systems. As a result, assessing teachers' perceptions of curricular progression and alignment is critical for understanding the structural weaknesses that influence learning continuity and subject discipline readiness.

Recent reforms in South Africa have sought to address such systemic challenges. The introduction of the Three-Stream Model aims to strengthen vocational pathways by integrating occupational subjects in Grades 8-9 (Western Cape Education Department, 2021). Similarly, national collaborations between the Department of Basic Education (DBE) and the Department of Higher Education and Training (DHET) have focused on aligning school curricula with post-school expectations (Branson & Whitelaw, 2025). Although promising, these reforms remain largely policy-driven, with limited empirical evidence regarding how the GET Electrical Technology syllabus specifically supports learners' readiness for FET specialisation. Few studies have investigated the extent to which the syllabus content, pedagogical orientation, and progression mechanisms prepare learners for advanced technical study. This lack of evidence illustrates a clear scholarly gap. It reinforces the need for a subject-specific evaluation of how the GET phase contributes to or hinders learner preparation for Electrical Technology FET pathways or subject specialisations such as Power Systems, Electronics, and Digital Electronics.

Beyond curriculum structure, teacher capacity and pedagogical practices play a critical role in determining the effectiveness of this transition. Studies show that many Technical and Vocational Education and Training (TVET) teachers possess limited pedagogical training and minimal exposure to current industrial practices (Ogbuanya & Shodipe, 2022). This lack of professional preparation undermines teachers' ability to facilitate effective, practice-oriented learning, particularly in technically demanding subjects like Electrical Technology (Msimango et al., 2024). Furthermore, resource constraints and exam-oriented approaches often deprioritise hands-on instruction, reducing learners' opportunities to engage meaningfully with practical applications (Mahajan, 2025). These contextual challenges raise critical questions about how the GET curriculum functions within real classroom environments and how effectively it prepares learners for the expectations of the FET phase. Empirical evidence on this issue remains limited, particularly concerning teachers' perceptions of curriculum coherence, skill progression, and content alignment across phases. The

existing literature has not yet provided a comprehensive understanding of how the GET syllabus bridges theoretical and practical learning for FET readiness (Ntholeng, 2024).

In South Africa, numerous studies have raised comparable concerns about how technical subjects are aligned throughout different phases. Khethwa (2020) discovered that, even with curricular revisions, many learners in technical schools struggle to connect basic concepts from lower grades to practical work in FET workshops. Chumchuen & Akatimagool (2023) also found that learners pursuing Electrical Technology specialisations frequently lack basic thinking and problem-solving skills, highlighting the gap between theory and practice. Coherently, these studies support international findings but highlight a local issue: an unequal implementation of technical disciplines across schools. Rural and township schools, in particular, have a shortage of skilled teachers and limited resources (Mncube et al., 2023). These gaps weaken the intended bridge between general and specialised learning, showing that the issue lies not only in curriculum design but also in everyday classroom practice.

Comparable case studies in the South African context back up this concern. Msezane (2020) pointed out that Electrical Technology teachers in KwaZulu-Natal regularly modify the GET syllabus to help learners meet FET requirements as prescribed in the CAPS documents of various subjects. This demonstrates a lack of planned progression between consecutive phases. Discovered in Gauteng Schools of Specialisation that, while early exposure to technical topics benefits learners, insufficient continuity between GET and FET results in fragmented learning (Motloung, 2025). These local findings align with a larger national issue: linking Vocational Education (VOC) to post-secondary and industry expectations. Strengthening the conceptual and practical link between the two phases is therefore critical if learners are to develop the skills and confidence required in South Africa's expanding technical and energy sectors. Hence, this study evaluated the GET Electrical Technology syllabus for transition into FET specialisations in Gauteng technical schools, South Africa.

The originality of this research lies in its focus on the underexplored area of curriculum alignment within Electrical Technology in the South African context. While prior studies have examined general vocational education challenges, few have analysed the pedagogical and structural transition from GET to FET in a subject-specific manner. This study contributes new insights by drawing on teachers' lived experiences and interpreting their perspectives through Bernstein's Pedagogic Discourse Theory, which emphasises how knowledge is classified, framed, and transmitted across educational levels. By foregrounding teachers' voices within this framework, the study provides a clearer understanding of how curriculum structure, classroom practice and knowledge progression intersect in real school environments. Therefore, this study not only investigates the effectiveness of the GET syllabus but also situates the findings within ongoing debates about vocational curriculum design and implementation. Specifically, it examines the curriculum content, alignment, and teaching strategies used within the GET phase, while analysing teachers' perceptions of progression and coherence between the two levels. The study is guided by two central research questions: (1) To what extent does the GET Electrical Technology syllabus provide the foundational knowledge and skills necessary for learners to transition successfully into FET specialisations? and (2) How do Electrical Technology teachers perceive the coherence and progression between the GET and FET syllabi, particularly in terms of content alignment and practical skill development? The findings are intended to support efforts to develop vocational learning pathways and to contribute to policy discussions about how the GET phase may better prepare learners for specialised technical education in South Africa and globally.

METHOD

This study employed a qualitative research approach **t**o explore how the General Education and Training (GET) syllabus of Electrical Technology prepares learners for transition into Further Education and Training (FET) specialisations. A qualitative approach is suitable for exploring meanings and experiences that individuals attach to social or educational phenomena (Adedoyin, 2020; Lim, 2025). It focuses on understanding participants' perspectives in depth, allowing the researcher to capture contextual nuances of classroom and curriculum implementation (Bailey, 2021). A case study design was adopted because it provides an in-depth examination of a bounded

system within its real-life context (Yin, 2018). This design was appropriate for studying the relationship between curriculum content, teacher practices and learners' preparedness within the South African Electrical Technology context. The study was theoretically grounded in Bernstein (2000) Pedagogic Discourse Theory**,** which explains how knowledge is selected, organized, and transmitted in educational settings. The theory guided the analysis of how knowledge is classified and framed across the GET and FET phases, revealing whether curriculum structure enables or restricts learner progression into specialised fields. The study was conducted between August and October 2025 across three education districts in Gauteng Province, South Africa, namely Gauteng North, Tshwane South, and Tshwane West. These districts were chosen because they host several technical high schools that offer both GET and FET phases of Electrical Technology, making them suitable contexts for examining curriculum transition and coherence.

The study population consisted of 20 Electrical Technology teachers from 17 technical high schools in the selected Gauteng districts. These were selected because they offered continuous Electrical Technology instruction from Grades 8 to 12. From this population, 11 Electrical Technology teachers were purposively selected as participants of this study. The selection criteria focused on teachers currently teaching Electrical Technology in both GET and FET phases, and on those with at least 3 years of teaching experience in the subject. In contrast, schools without both phases or where teachers did not meet these criteria were not included in the study. This ensured that only experienced teachers with direct knowledge of the curriculum transition were interviewed, enhancing data quality and the trustworthiness of the findings and results. The sample size of 11 participants was determined based on data saturation, a principle commonly applied in qualitative research. During data collection, new interviews were conducted until no new insights or themes were emerging. By the eleventh interview, responses had begun to repeat, indicating that sufficient depth and variety of information had been achieved. The final sample size was therefore adequate to capture meaningful patterns and experiences across the study sites.

Data were collected using semi-structured interviews and document analysis. Semi-structured interviews provided participants with the flexibility to share their experiences, perceptions, and challenges in teaching Electrical Technology, while enabling the researcher to probe for detailed explanations (Karatsareas, 2022). Eleven face-to-face interview sessions were conducted at participants' schools and lasted approximately 45-60 minutes each. Document analysis involved reviewing the Annual Teaching Plans (ATPs**)** and the Curriculum and Assessment Policy Statement (CAPS) to examine how the GET curriculum content aligns with or fails to support FET-level requirements. This process helped identify gaps in content progression and pedagogical continuity. The combination of these two methods allowed for data triangulation, enhancing the validity and credibility of the findings by cross-verifying teachers' perspectives with curriculum documentation. The main interview questions that were used to collect data from Electrical Technology teachers are shown in Table 1 below.

Table 1. Semi-Structured Interview Questions

No.	Semi-structured interview questions
1	How effective do you think the current GET syllabus is in preparing learners for the FET Electrical Technology phase?
2	Which content areas in the GET syllabus do you find most and least relevant for FET learning?
3	What teaching approaches do you use to help learners transition smoothly from GET to FET?
4	What challenges do you face when teaching learners who are progressing from GET to FET?
5	How do resources and school conditions influence the way you implement the syllabus?
6	What changes would you suggest to improve curriculum alignment between the two phases?

Document analysis complemented the interviews by examining the Electrical Technology Curriculum and Assessment Policy Statement (CAPS), Annual Teaching Plans (ATPs) and selected lesson plans of teachers. This analysis helped identify how GET content links to, or fails to link to, the concepts, content, and skills required in the FET phase.

Data were analysed using thematic analysis, following the steps outlined by Salmona & Kaczynski (2024). This involved transcribing interview data, coding textual segments, identifying recurring patterns, and generating themes that reflected the structure and effectiveness of the GET

syllabus in preparing learners for FET. Thematic analysis enabled the researcher to interpret both explicit and underlying meanings in participants' responses and connect them to Bernstein's theoretical concepts of classification and framing.

To ensure trustworthiness, the study applied criteria of credibility, dependability, and confirmability. Member checking was conducted to verify the accuracy of interview interpretations, and data triangulation (interviews and documents) was used to enhance analytical rigour. Detailed descriptions of context and procedures were maintained to support transferability. Ethical clearance was obtained in accordance with institutional and national research standards. Participants provided informed consent after being briefed on the purpose, procedures, and voluntary nature of the study. They were assured of their right to withdraw at any point without consequence. To ensure confidentiality, pseudonyms were assigned to all participants, and identifying details were removed from transcripts. Data were securely stored and used solely for research purposes, ensuring adherence to professional ethical guidelines.

RESULTS AND DISCUSSION

Results

This section presents and interprets findings from semi-structured interviews and document analysis, structured around the two research questions that guided this study. To reiterate, the purpose of this study was to explore the General Education and Training syllabus for Electrical Technology to support transition into Further Education and Training specialisations. Thematic analysis was employed to extract key themes related to foundational knowledge, curriculum alignment and practical preparedness. All discussions were informed by Bernstein's Theory of Pedagogic Discourse, which helped interpret how knowledge is selected, organised, and transmitted in curriculum settings, particularly where vertical and horizontal discourse structures are critical for progression.

To reiterate, the selected sample comprised 11 Electrical Technology teachers, referred to as Teachers A-K, each reflecting a unique teaching context across Gauteng technical schools. Teacher A and Teacher B taught at well-resourced urban schools and oversaw both Grades 9 and 10, providing insights regarding curriculum continuity. Teachers C and D worked in township schools with limited workshop resources, highlighting the contextual constraints. Teacher E and Teacher F were experienced senior teachers and subject heads responsible for mentoring new teachers. Still, Teachers G and H were relatively new to the field, with exactly 3 years of teaching experience, and brought new insights to syllabus implementation. Their combined experiences enabled the study to identify differences in the interpretation, implementation and perceived alignment of the Electrical Technology syllabus across educational environments. Such representation is critical in qualitative research, as Singh et al., (2024), emphasize the value of different voices in increasing the depth and legitimacy of case study findings.

Findings and Discussions on Research Question 1

"To what extent does the GET Electrical Technology syllabus provide the foundational knowledge and skills necessary for learners to transition successfully into FET specialisations?"

Electrical Technology teachers' perceptions and curriculum documents reveal a significant gap between what is taught in the GET phase and what is required for success in the FET phase. Across the interviews, Electrical Technology teachers consistently expressed concerns about the apparent treatment of key Electrical Technology concepts in Grades 8 and 9, particularly regarding the development of practical skills and the cognitive progression of learners. During semi-structured interviews, Teacher A elaborated that, "Learners get to Grade 10 without having even touched a multimeter. They know some theory, but they cannot apply it to practical work." This lack of readiness reflects what Bernstein (2000) would define as a breakdown in vertical discourse, in which knowledge is not accumulated in a hierarchical or progressively structured manner across educational phases. Emphasise that for Vocational Education (VOC) to be effective, it must move beyond

abstract theory and develop contextual, applicable skills relevant to the learner's future career field (McGrath & Yamada, 2023).

Teachers B, C, and D supported the concern, stating that the GET syllabus is extremely theoretical and does not involve learners in actual practical work. Similarly, Teacher B also noted that a lack of hands-on experience leads to poor skill transfer until learners reach FET. In contrast, Teacher C pointed out that "Without workshop exposure, learners cannot relate theory to practice." Teachers E and F, both experienced teachers, recognised the syllabus's objective to convey key electrical principles but argued that it lacks depth and development towards FET specialisations such as Power Systems and Digital Electronics, among others. They believed that, while theoretical grounding is necessary, it must be supplemented by structured application to maintain learning continuity, which is compatible with Suci et al., (2022), belief that practical application increases vocational comprehension. Similarly, although less experienced than other teachers, Teachers G and H agreed that the syllabus did not prepare learners for real FET activities such as circuit wiring or component testing, demonstrating a claim about the lack of vertical knowledge progression (Bernstein, 2000). Teachers I, J, and K, who taught entirely at the GET level, discovered that their learners frequently struggled with identifying fundamental tools and with safety practices, indicating the need for more integrated, practical activities to support early conceptualisation. These perspectives collectively affirm that the GET curriculum lacks logical scaffolding toward the FET phase, which is consistent with Yarberry & Sims (2021) observation that poorly designed practical learning impedes occupational growth (Yarberry & Sims, 2021). Hence, the study examined the extent to which the GET Electrical Technology syllabus provides the foundational knowledge and skills necessary for learners to transition successfully into FET specialisations.

Similarly, document analysis supported these views. The curriculum content in the GET phase was predominantly descriptive, with little scaffolding toward technical competencies expected in the FET phase, especially for Electronics specialisations. For example, Teacher C revealed that "While circuit theory was included under Basic Principles of Electricity in Grade 9, there was no structured opportunities for learners to apply this knowledge practically using tools, simulations, or real-world scenarios". Ogbuanya & Shodipe (2022), underscores that learners cannot develop vocational expertise without participating in knowledge-rich practical tasks that simulate workplace realities. Majola (2024) claims that many South African vocational programmes remain overly theoretical, with practical components often sidelined due to resource shortages and rigid syllabus. Thus, this poses a concern about how well the GET syllabus prepares learners for transition to FET specialisations of Electrical Technology? This concern reinforces the view that the GET syllabus, constrained by its theoretical bias and limited practical exposure, does not sufficiently prepare learners for the demands of FET Electrical Technology specializations, thereby widening the gap in curricular continuity. As Ntholeng (2024) highlight, weak curriculum coherence and limited practical orientation in South African schooling often hinder learners' ability to progress effectively into more specialized vocational pathways. Resultantly, this shows that the GET syllabus does not give learners the solid grounding they need for FET Electrical Technology. Its focus on theory over practical skills leaves learners underprepared and widens the gap between the two phases.

Furthermore, Teacher B resonated this concern: "We're basically forced to reteach everything in Grade 10. The gap is too wide." This aligns with research by Mushwana et al., (2024), who found that weak curriculum continuity in African TVET systems results in lowered learner confidence and higher dropout rates. The issue is not just one of content inclusion, but of sequencing and pedagogic strategy, two key dimensions Bernstein (2000), highlights as central to curriculum design. Also, Teacher D confirmed this claim by explaining that "Grade 10 Electrical Technology learners enter the FET phase without the solid foundation they need, as the GET syllabus often introduces concepts without ensuring mastery or application (Bernstein, 2000). This evidence reveals that while some basic principles are covered, the GET syllabus does not adequately provide the depth of knowledge or skills necessary for a smooth transition into FET phase. In the same way, Singh et al., (2024) point out that when vocational curricula are broken up and lack a clear flow, learners often battle to develop the skills they need at the next level. Gonczi (2020) reminds us that without proper support and a balance of theory and practice, the move from general to specialized vocational learning becomes

difficult and discouraging for many learners. Taken together, this shows that the GET Electrical Technology syllabus is not giving learners the solid grounding they need to step confidently into FET specializations.

Subsequently, the findings reveal that the GET syllabus lacks the structured, progressive and application-oriented content needed to serve as a bridge into specialized technical learning areas of Electrical Technology in the FET phase. This misalignment represents more than a missed academic opportunity, it undermines the very aim of Electrical Technology as a vocational pathway, which was brought in place to guide equip learners for related field of work. Addressing this misalignment is essential if South African learners are to benefit from Vocational Education (VOC) that prepares them not only for FET success but for meaningful participation in the country's falling economy.

Findings and Discussions on Research Question 2

"How do Electrical Technology teachers perceive the coherence and progression between the GET and FET syllabus?"

When Electrical Technology teachers were asked about curriculum coherence, teachers overwhelmingly felt that the GET and FET syllabus functioned in isolation, with little attention paid to content progression or pedagogical continuity. During semi-structured interviews Teacher C remarked, "In Grade 9, learners just identify tools, but there's no transition to using them. Then in Grade 10, they're expected to wire circuits. It's a huge jump for learners." This disconnect mirrors what Bernstein (2000), describes as a weak classification and framing of knowledge where boundaries between subjects or phases are not clearly aligned and pedagogical control is fragmented. In this study, Electrical Technology teachers clearly see little progression between the GET and FET syllabi. Hence, learners meet concepts in isolation, without the steady build-up needed to bridge the two phases. This resonates David (2023) point that vocational curriculum in South Africa is often disjointed, making it hard for learners to carry skills forward to the next phase. In line with the research question, teachers believe the transition from GET to FET is poorly structured, leaving learners unprepared for the demands of the Electrical Technology FET syllabus.

Teachers G, H and I elaborated by emphasizing that, while the GET syllabus contains fundamental topics, it does not demonstrate how they translate into advanced competencies in FET specializations. In addition, Teacher H stated that "Learners memorize terms in Grade 9 to progress, but in Grade 10, they suddenly face complex wiring diagrams without knowing the logic behind them." Teachers J and K, on the other hand, suggested that the Department's limited teacher support and unclear progression guidelines contributed to the problem. Their views support David (2023) claim that Vocational Education (VOC) must openly scaffold knowledge across levels so that learners can gradually develop cognitive and practical competencies required in the FET phase and in the electrical industries. Hence, it was significant for this study to to explore how the GET curriculum supports or fails to support smooth curriculum transition in Electrical Technology.

On the similar vein, Teacher D further added, "There's no continuity in how the topics evolve, it feels like two separate courses with no relationship linking the two." Such misalignment limits learners' ability to internalize key concepts over time and reduces the effectiveness of skill acquisition, a concern also raised by Farran & Nunez (2025), who advocate for integrated learning routes in Vocational Education (VOC). This points to a real weakness in how the curriculum is structured, where learners do not get a chance to gradually build on what they have learned. As Reiser (2023) explains, successful vocational learning depends on clear scaffolding that connects knowledge across grades, so learners are not left to figure out difficult concepts on their own. Felder & Brent (2024) also warn that when the curriculum is split, learners struggle to develop and apply practical skills effectively. In line with these concerns, Electrical Technology teachers feel that the GET and FET syllabi are divided and do not provide the smooth progression learners need from the GET to the FET phase. Furthermore, teachers noted that in Grade 10, they often have to reteach basic skills, which wastes time for more advanced work. "Learners can feel lost and frustrated when concepts suddenly become harder without proper preparation", added teacher E. Overall, this shows that the lack of coherence between GET and FET makes the transition much harder for learners than it should be.

From the document analysis, it was clear that while the GET syllabus outlines foundational content, it does not intentionally prepare learners for the complexity of tasks in the FET phase. For instance, Digital Logic circuits, a major topic in Digital Electronics, are absent in Grades 8 and 9, yet are heavily emphasised in Grade 10. Teacher D mentioned, "Learners are just expected to pick it up as they go. But without a base, they get lost." This lack of pedagogic sequencing undermines the cognitive and technical scaffolding required for success in technical fields. Rintala & Nokelainen (2020) point out that in Vocational Education (VOC), cumulative learning is vital, each phase must support the next. Without coherent alignment, even the most competent learners struggle to make sense of the progression. Moreover, many teachers felt that inadequate support structures, such as teaching aids, instructional resources and subject-specific teacher development, compounded the lack of consistency. As Teacher F observed, "We're supposed to guide learners across phases, but the system does not equip us with the materials or training to do that properly." In relation to Research Question 2, these insights show that teachers perceive a clear break in coherence between the GET and FET syllabi. Instead of a smooth transition, learners face gaps that undermine their ability to build on prior knowledge. Electrical Technology teachers also stressed that without proper resources and training, they struggle to bridge this gap themselves. This means the progression is disjointed, leaving learners underprepared for advanced Electrical Technology specialisations in the FET band.

The collective responses of Teachers A-K paint a clear picture of how a lack of curriculum consistency affects both teaching and learning in the Electrical Technology subject in Gauteng technical schools. Their reflections reveal that, despite different school environments and teaching experiences, they all face the challenge of connecting to an Electrical Technology curriculum framework. As a result, these findings emphasise the need for a revised Electrical Technology syllabus which involves vertical progression, emphasises practical readiness for FET specialisations, and supports teacher professional development to ensure consistent content delivery. This aligns with Young & Hordern (2022), who advocate curriculum coherence as critical for long-term Vocational Education (VOC) success.

In summary, the findings for Research Question 2 confirm a troubling disconnect between the GET and FET syllabi regarding content progression and skill development. While the GET phase introduces basic concepts, it does so in isolation, with limited effort to support learners in applying these ideas to real-world contexts or to the more complex work in the FET phase. This weak rationality undermines the role of Vocational Education (VOC) in South Africa as a meaningful route to employment and further study.

CONCLUSION

This study concludes that while the GET Electrical Technology syllabus in South African technical schools attempts to lay a foundation for Further Education and Training (FET) specialisations, it falls significantly short in doing so. The findings revealed that the curriculum lacks both depth and coherence to prepare learners for advanced technical content in subjects such as Digital Electronics, Power Systems, and Electronics. Teachers consistently emphasised the lack of structured progression, inadequate practical learning, and weak content alignment between the GET and FET phases. These gaps limit learners' ability to transfer knowledge into hands-on tasks and result in a shaky transition into the FET phase, where higher-order thinking and practical problem-solving are critical.

Moreover, the study found that the foundational concepts taught in Grades 8 and 9 are not only overly theoretical but also disconnected from the skills required in Grade 10, creating a pedagogical divide that teachers must bridge. In light of Bernstein's theory of pedagogic discourse, this lack of vertical curriculum alignment hinders learners' access to systematic knowledge and restricts their progression into higher levels of vocational understanding. From a broader perspective, these findings speak to a pressing issue in curriculum studies when Vocational Education (VOC) is treated as a loosely connected series of phases rather than a coherent learning journey; learners and systems both lose.

In the global and Inovasi Teknologi Pendidikan Journal context, where Vocational Education (VOC) is increasingly viewed as a driver of inclusive growth and social transformation, South

Africa's experience highlights the need for curriculum design that is not only internally aligned but also responsive to changing technological and workplace demands. Therefore, this study argues for an urgent re-evaluation of the General Education and Training (GET) Electrical Technology syllabus to ensure stronger progression, improved practical integration and better preparedness for specialisation. Doing so would not only improve learner outcomes locally but also contribute to the international conversation on how Vocational Education (VOC) systems can be designed to equip learners for meaningful futures.

Based on these findings, educational officials in the Gauteng Department of Education (GDE) and throughout South Africa should further develop curriculum reform by adopting a competency-based approach that integrates knowledge, abilities, and attitudes aligned with workplace realities. Such a model should prioritise problem-solving, innovation, and adaptability competencies that enable learners to participate effectively in the global economy (Alainati, 2021). Correspondingly, competency-based frameworks would enable learners to understand technical theory and apply it in a variety of contexts using modern electrical tools and technologies. This policy orientation would also necessitate investments in teacher professional development, industry partnerships, and resource allocation to create authentic learning environments. This will further help post-matric learners to serve the local and global needs of the Electrical Engineering industry as a whole.

ACKNOWLEDGEMENT

The author gratefully acknowledges the support of the participating Electrical Technology teachers and schools in Gauteng Province, South Africa, whose contributions and insights made this study possible. Special thanks also go to the Gauteng Department of Education (GDE) for granting access to the relevant curriculum documents. The constructive guidance from colleagues and supervisors throughout the research process is sincerely appreciated. Finally, the author would like to thank the editorial team and reviewers of the Jurnal Inovasi Teknologi Pendidikan for their thoughtful feedback, which greatly improved the quality of this manuscript.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (82-92)
Online: http://journal.uny.ac.id/index.php/jitp

Exploring the impact of YouTube and instructional videos on learning outcomes: A comparative study

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ARTICLE INFO

Article History
Received:
13 February 2026;
Revised:
23 March 2026;
Accepted:
23 March 2026;
Available online:
31 March 2026.

Keywords
Instructional videos; Knowledge; Records management; Skills; YouTube videos

ABSTRACT

The YouTube platform has become a key learning tool, providing free video content. Meanwhile, with a vast video database and a platform focused on entertainment, many question whether YouTube video content aligns with pedagogical objectives. Therefore, this study aims to compare the learning outcomes of students who use YouTube videos and instructor-developed videos (IDVs) in archival management learning. Using a quantitative approach based on a quasi-non-equivalent control group design with a post-test-only design, this research focuses on test instruments to measure cognitive and psychomotor learning outcomes involving 79 students enrolled in the Records Management course at the Faculty of Vocational Studies, Universitas Negeri Yogyakarta. Data analysis consisted of normality and homogeneity tests. To determine differences between the two groups, the Mann-Whitney U test was conducted in RStudio. The results showed that 1) there was no significant difference in cognitive achievement between students who learned using YouTube videos and instructional videos, and 2) there was a significant difference in psychomotor achievement between students who learned using YouTube videos and instructional videos. This finding indicates that YouTube videos can support students' cognitive thinking; however, they have not achieved greater skill gains than videos developed with practical learning characteristics. Future studies may identify factors influencing learning outcomes in both groups to examine the extent to which instructional media use supports learning achievement, particularly in the psychomotor domain.

How to cite:
Yuliansah, Sutirman, Dwihartanti, M., & Sholikah, M. (2026). Exploring the impact of YouTube and instructional videos on learning outcomes: A comparative study. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 82-92. https://doi.org/10.21831/jitp.v13i1.94033

INTRODUCTION

The era of online learning continues to evolve and persist even after the Covid-19 pandemic, driven by its flexibility and high adaptability, which allow students to learn anytime, anywhere. The development of MOOCs, learning management systems (LMS), and web-based platforms has also led to the emergence of various video-based learning content used in asynchronous learning (Mohamed & Shoufan, 2022). In higher education, asynchronous learning is commonly implemented by providing a series of videos for students to analyse. At the end of the learning process, students are required to conduct experiments or complete quizzes to evaluate their learning outcomes (Zull, 2002).

Video content is a key component of asynchronous learning, as it facilitates knowledge construction by delivering content in the absence of instructors in online environments (Suen & Hung, 2024). Asynchronous learning supported by video content offers cognitive benefits (e.g., learning and retention) and psychological advantages (e.g., motivation and learning attitudes). It provides clearer representations of knowledge through dual-channel coding (Gaudin & Chaliès, 2015). This is in line with Dual Coding Theory (DCT) proposed by Clark & Paivio (1991), which explains that individual process information through two systems: verbal and non-verbal (visual). The integration of visual information with verbal explanations enables the formation of stronger knowledge structures, particularly in long-term memory. Furthermore, the process of constructing knowledge through active engagement with video content aligns with the principles of experiential learning (Kolb, 1984).

However, the increasing demand for video-based content has encouraged the use of video resources beyond formal educational contexts (Christopoulos et al., 2023; Martínez et al., 2024). One of the most widely used platforms is YouTube, which provides freely accessible content for both formal and informal learning (Fikri et al., 2022). Despite its widespread use, the adoption of YouTube in educational settings remains debated, as the platform is not specifically designed to support instructional objectives (Greeves & Oz, 2023; Nacak et al., 2020).

On the other hand, videos designed specifically for learning environments, whether online or offline, must meet certain criteria to avoid imposing additional cognitive load on learners, one of which is the principle of segmenting (Lee & Tsai, 2018). This aligns with the Cognitive Theory of Multimedia Learning (CTML) proposed by Mayer (2014a), which emphasises that multimedia design (audio and visual) should aim to reduce extraneous cognitive load. In addition, Mayer (2003, 2014a, 2014b) highlights several key principles in multimedia design, including coherence, signalling, spatial contiguity, and temporal contiguity.

The coherence principle emphasises that all content presented in a video should be relevant and aligned with instructional objectives. Meanwhile, the signalling principle refers to the use of cues or highlights to direct learners' attention to essential information, thereby helping them focus on key elements of the content. Finally, the segmenting principle highlights that learning materials should be presented in smaller, manageable parts to be processed more effectively, given learners' limited cognitive capacity. These principles have been empirically shown to reduce excessive cognitive load through dual-modality design and to enhance students' learning outcomes (Candido & Cattaneo, 2025).

Given the critical role of video in supporting learning objectives, video-based content in asynchronous learning should be carefully designed in accordance with the principles of the Cognitive Theory of Multimedia Learning (CTML) (Greenberg et al., 2021). However, the increasing adoption of social media platforms such as YouTube in educational contexts has become more widespread due to their accessibility and ease of use (Roy, 2023).

Despite this, YouTube is not specifically designed to follow multimedia learning principles or to support instructional processes (Allgaier, 2019; Greeves & Oz, 2023). As a free and open platform, most video content on YouTube is primarily developed for entertainment, as it serves as a social media platform for sharing and consuming video.

The growing use of YouTube for educational purposes in higher education has attracted increasing attention from researchers. For example, a study by Guaya et al., (2024) examined integrating YouTube with a Project-Based Learning approach in higher education and found that this integration enhances student engagement and knowledge and skill development in chemical engineering. In the field of informatics, YouTube is widely used by students as a learning resource, offering a variety of instructional content, including tutorials, lectures, and demonstrations (Fergina et al., 2025). Beyond STEM disciplines, YouTube is also widely used in higher education contexts, particularly in English as a Foreign Language (EFL) instruction. Studies by Al-Mubireek (2025) and Menggo et al., (2025) show empirical evidence that the use of YouTube brings positive and significant impacts in terms of increasing students' learning autonomy, speaking skills, and improving the overall quality of learning in the EFL context. In the field of administration, Roy

(2023) found that YouTube use among Master of Business Administration (MBA) students in Bangladesh is associated with improved academic performance.

Students' perceptions of why they prefer using YouTube for learning have been explored by Burhanlı & Bangir (2021), who found that YouTube content aligns with students' interests and learning needs, is easy to use, and helps overcome the limitations of synchronous learning in campus settings. In addition, YouTube's popularity in learning contexts is also influenced by its vast collection of video content (Chintalapati & Daruri, 2017). The platform is considered user-friendly, with simple navigation that allows users to easily search for relevant content by entering specific keywords based on their learning needs (Fyfield et al., 2021; Mohamed & Shoufan, 2022).

Although previous studies have provided empirical evidence that learning through YouTube videos is accessible, engaging, and can positively impact learning performance, several researchers have raised concerns about its use in educational settings. For example, by Ergul (2021), Fares et al., (2023) and Mohamed & Shoufan (2022), who question whether all video content on YouTube is aligned with learning content, developed based on achieving learning objectives, or supporting the achievement of specific competencies. Meanwhile, the ranking system on YouTube prioritises views, so that people who want to learn are presented with popular videos rather than quality or learning-objective-aligned content (Abbas et al., 2025). Furthermore, free videos are also unlikely to meet the quality standards students need in the classroom (Roth et al., 2017).

In contrast to YouTube-based content, instructional videos can be generally defined as videos developed in alignment with the curriculum to support the achievement of learning objectives (Lamontagne et al., 2021). In educational contexts, such videos are intentionally designed based on the principles of the Cognitive Theory of Multimedia Learning (CTML). For instance, the signalling principle is believed to help learners focus on essential information, thereby improving the learning process (Ragazou & Karasavvidis, 2023).

Furthermore, an experimental study by Jing et al., (2025) examined the effects of combining visual and verbal elements (dual-modality) in videos with and without text. The findings indicate that videos with text may lead to shorter fixation duration and frequency during text processing, increased extraneous cognitive load, and reduced germane load, ultimately resulting in lower learning performance.

Another study by da Silva & Oliveira (2023) found that videos designed based on CTML principles can improve content quality and facilitate knowledge transfer, thereby enhancing learning outcomes. Additional empirical evidence summarised by Hew & Lo (2020) also indicates that self-developed videos can improve students' learning performance. These findings suggest that both Cognitive Load Theory and the Cognitive Theory of Multimedia Learning remain relevant, as they emphasise the critical role of multimedia design quality in influencing learning effectiveness (Noetel et al., 2022).

Previous studies have extensively examined the impact of video-based learning on learning outcomes, either through instructional videos developed according to CTML principles or through YouTube content. For instance, several studies have investigated the effectiveness of instructional videos (da Silva & Oliveira, 2023; Hew & Lo, 2020; Ragazou & Karasavvidis, 2023), consistently reporting positive impacts on teaching and learning processes. Similarly, other studies have explored the use of YouTube-based videos and found generally positive effects on learning outcomes (Al-Mubireek, 2025; Guaya et al., 2024; Menggo et al., 2025; Roy, 2023).

However, most of these studies focus on a single type of video, either instructional videos or YouTube-based content. Direct comparisons between these two types of video remain limited, particularly in examining how instructional videos developed according to CTML principles differ from YouTube videos in their influence on learning outcomes.

Therefore, this study aims to examine the differences in learning outcomes, both knowledge and skills, between students who learn using YouTube-based videos and those who learn using instructional videos in asynchronous learning environments in higher education. The novelty of this study lies in its direct experimental comparison of these two types of videos. While YouTube content is generally not designed for instructional purposes, instructional videos are developed in line with CTML principles to support the achievement of learning objectives. The findings of this study are expected to provide a new perspective on whether educators still need to create their own

instructional videos. This is particularly important given that developing instructional videos often requires significant time, preparation, and financial resources (Fyfield et al., 2022; Xu et al., 2025).

METHOD

This study adopts a quantitative, quasi-experimental design, specifically the posttest-only nonequivalent control group design. Two groups were selected through non-random sampling by utilising existing classes enrolled in an archival management course during the 2024-2025 academic year. Therefore, the group assignment was not random. The purpose of this design is to compare learning outcomes, including both knowledge and skills, between the two groups in an asynchronous learning context in higher education. The assignment of experimental and control groups was based on pretest results (knowledge) to identify students' initial conditions.

The study population consisted of 79 students enrolled in the Archival Management course at the Faculty of Vocational Studies, Universitas Negeri Yogyakarta (UNY), during the 2024-2025 academic year. A total sampling technique was employed, in which all members of the population were included as research participants. The determination of the experimental and control groups was based on pretest results: the class with the lower mean score was assigned to the experimental group, and the class with the higher mean score was assigned to the control group (see Table 1).

Table 1. Experiment Research Design

No.	Group	Pre-Test	SD	Treatment	Posttest
1	Experiment Group	53.87	17.26	Using Instructional Videos (X_1)	O_2
2	Control Group	55.48	16.89	Using YouTube (X_2)	O_4

Source: (William & Jurs, 2009).

The experimental group received the treatment by learning through instructor-developed Digital Archival Videos, that had undergone a development process as described by (Sutirman et al., 2024), Meanwhile, the control group learned using Digital Archival Videos sourced from YouTube, selected using the keyword "alphabetical filing system." The two top-ranked videos from the search results were chosen as learning materials for the control group (see Figure 1). In the first session, students were introduced to the experimental procedure and completed the pretest. Subsequently, students engaged in independent learning from the second to the fourth sessions using the LMS platform. Skill assessment was conducted through independent practicum tasks, while cognitive outcomes were measured using a test instrument (see Figure 2).

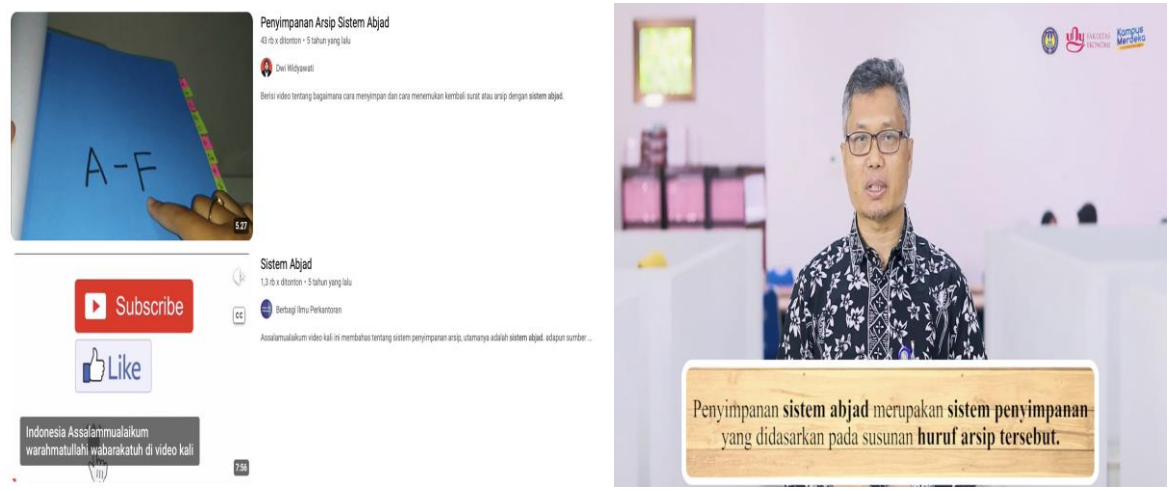

Figure 1. Video Sample

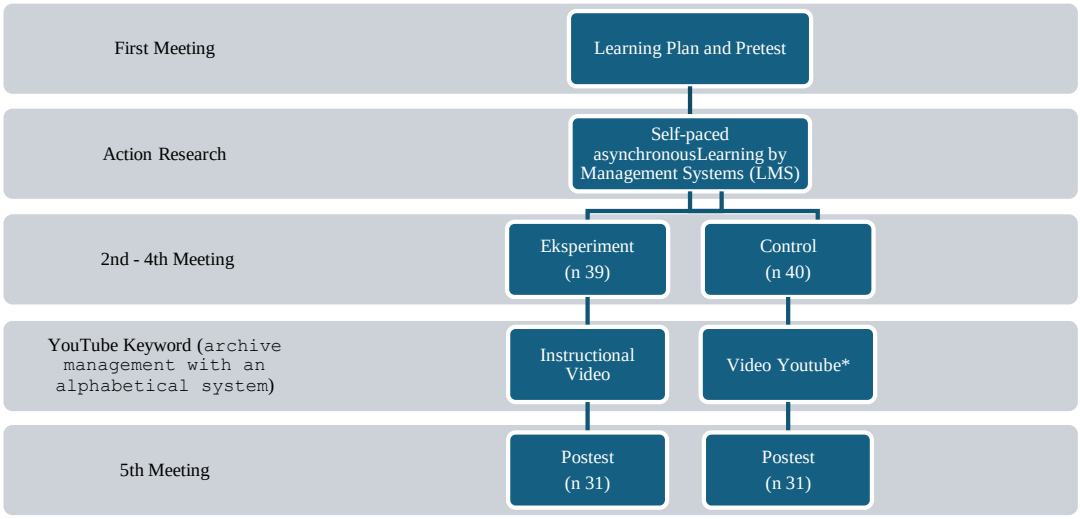

Figure 2. Research Procedure

Based on several considerations, 17 students did not participate in the learning activities, leaving 62 students whose data were included in the final analysis. A study by Besekar et al., (2023) concluded that the sample size for testing any novel approach essentially required a minimum of 24 participants in each group. Data were collected using both test and non-test techniques. The test instrument consisted of multiple-choice questions designed to measure cognitive learning outcomes, comprising 15 items with five answer options each. Meanwhile, skill-based learning outcomes were assessed using a non-test approach through a holistic scoring rubric with four levels: very good, good, poor, and very poor.

The validity of both test and non-test instruments was evaluated through expert judgment involving two experts in archival management and educational assessment. The results indicated that all items were aligned with the intended indicators and were deemed appropriate for use. The test instrument's reliability was confirmed using Cronbach's alpha (0.813), indicating good internal consistency. For the non-test instrument, reliability was ensured through a structured rubric, and the course instructor conducted assessments to maintain scoring consistency.

Data analysis included descriptive statistics, normality testing, and homogeneity testing. The results of the normality test indicated that the data were not normally distributed; therefore, a non-parametric statistical test was applied. Hypothesis testing was conducted using the Mann-Whitney U test to examine differences in learning outcomes between the experimental and control groups. All analyses were performed in RStudio.

RESULTS AND DISCUSSION

Results

This section presents the research findings, including respondent demographics, descriptive statistics, normality and homogeneity tests, and hypothesis testing using the Mann-Whitney U test. The demographic characteristics of the respondents are presented in Table 2.

Table 2. Demographic of the respondent

Information		Control		Experiment	
		n	%	n	%
Gender	Male	24	77.41	25	80.64
	Female	8	22.59	6	19.36
Year of Birth	2004	7	22.58	9	29.03
	2005	24	77.42	22	70.97

Table 2 shows the demographic characteristics of the respondents in the control and experimental groups. In terms of gender, male students constituted the majority in both groups,

accounting for 77.41% in the control group and 80.64% in the experimental group. Regarding year of birth, all respondents were born between 2004 and 2005, indicating that the entire sample belongs to Generation Z. Table 3 presents Informative descriptions of the mean, standard deviation, minimum, maximum, and count of those variables.

Table 3. Statistics Descriptive

	Control		Experiment	
	Knowledge	**Skill**	**Knowledge**	**Skill**
Mean	70.32	58.53	72.58	74.95
SD	17.79	13.83	17.69	12.07
Minimum	30	43.88	40	56.66
Maximum	100	84.44	100	95.27
Count	31	31	31	31

Table 3 shows the differences in knowledge and skill test results between the two groups. The results indicate that the experimental group achieved higher mean scores on both knowledge and skill outcomes than the control group.

In particular, the difference in skill scores between the two groups was relatively substantial, with a mean difference of 16.42. This suggests that the instructional videos may be associated with better student performance in understanding and applying the alphabetical filing system.

To determine whether the differences between the two classes are statistically significant, it is necessary to conduct statistical tests. Therefore, the following section presents the results of the normality and homogeneity tests for both the knowledge and skills variables (Tables 4 and 5).

Table 4. Shapiro-Wilk Test Result

No.	Variable	W Statistic	p-value	Conclusion
1	Knowledge	0.94995	0.01328	The data are not normally distributed.
2	Skills	0.92726	0.00124	The data are not normally distributed.

Table 5. Levene's Test Result

No.	Variable	F Value	p-value	Conclusion
1	Knowledge	0.0478	0.8277	Variances are homogeneous
2	Skills	0.0012	0.9724	Variances are homogeneous

Table 4 presents the results of the Shapiro-Wilk test, indicating that the data for all variables are not normally distributed. Table 5 shows the results of Levene's test, confirming that the data are homogeneous. Based on these findings, a non-parametric test was employed. The Mann–Whitney U test was used to examine whether there were significant differences in learning outcomes (knowledge and skills) between the experimental and control groups. The results of the hypothesis testing are presented in Table 6.

Table 6. Mann-Whitney U Test

No.	Variable	M-W U Test	Wilcoxon W	Z	Sig.	Conclusion
1	Knowledge	446.000	942.000	-0.493	0.622	H0 Accepted
2	Skill	166.000	662.000	-4.434	0.000	H0 Rejected

Table 6 confirms the Mann–Whitney U test results. For the knowledge aspect, the significance value was 0.522 (> 0.05), indicating that there is no statistically significant difference in knowledge learning outcomes between the two groups. In contrast, for the skill aspect, the significance value was 0.000 (< 0.05), indicating a statistically significant difference in skill learning outcomes between the two groups.

Discussion

This discussion section addresses the research questions, the implications of the findings for the adoption of video in learning, and the study's limitations. First, regarding knowledge, the findings indicate that there is no significant difference in knowledge learning outcomes between the control

and experimental groups. This suggests that both types of video are effective at delivering content and supporting students' understanding of the material. Although YouTube videos are not specifically designed or developed based on structured instructional design principles, they still serve as effective learning media. This finding implies that both types of videos can provide sufficient knowledge support and facilitate students' ability to construct understanding from the presented content, which may contribute to knowledge retention in long-term memory.

Several factors may explain this result. Video-based learning, whether through YouTube or instructional videos, allows students to pause, replay, speed up, or focus on specific segments they find difficult (Liao & Wu, 2023). This flexibility enables students to regulate their own learning process. In addition, both types of video are accessible online, allowing students to learn anytime and anywhere, and are generally easy to use (Insorio, 2025; Mohamed & Shoufan, 2022).

These findings are consistent with previous studies. For example, Guaya et al., (2024) reported that the integration of YouTube videos within a Project-Based Learning (PBL) approach can support improved learning performance in chemical engineering education. Furthermore, this result complements earlier findings by Roy (2023), which suggest that YouTube videos can support learning in theory-based administrative subjects at both undergraduate and postgraduate levels.

Second, the findings indicate a statistically significant difference in skill-related learning outcomes between the experimental and control groups. This suggests that instructional videos may be associated with better skill acquisition than YouTube-based videos. One possible explanation is that instructional videos are developed in alignment with learning objectives and follow a structured design process, including needs analysis, design, and development stages guided by CTML principles. In contrast, YouTube videos are generally produced to meet broader content demands and may not be specifically aligned with instructional goals.

The integration of multimedia principles such as segmentation, signalling, and coherence (Mayer, 2014a, 2014b) in instructional videos may support the delivery of procedural information more effectively, particularly in tasks such as learning the alphabetical filing system.

The findings are consistent with previous studies. For instance, reported that video-based learning can support improvements in student performance. These results also suggest that using video facilitates students' learning, potentially contributing to their academic achievement. In addition, the better performance in skill-related learning outcomes observed in the group using instructor-developed videos compared to YouTube-based videos further supports earlier studies indicating that not all YouTube content is suitable for instructional use (Ergul, 2021; Fares et al., 2023; Mohamed & Shoufan, 2022). This is particularly relevant in learning contexts that require the development of practical skills, where instructional alignment and structured design are critical.

Third, the results of this study have significant implications for instructional practice, particularly in subjects with practical components. Educators need to give special attention when implementing independent (asynchronous) learning through LMS or other media. This study is important in the era of digital learning, as the appropriateness of video selection depends on educators. Therefore, educators should provide relevant learning resources for students in digital learning contexts (Yadav, 2023). However, video-based instructional media need not be developed independently. Given the constraints of time, cost, and effort, educators may utilise video creation and editing tools powered by artificial intelligence as an alternative (Fyfield et al., 2022; Xu et al., 2025).

Despite successfully comparing the impact of the two types of video on learning outcomes, this study has several limitations. First, the sample size was relatively small (n = 62), which limits the generalizability of the findings. Second, the researcher intervened in the selection of YouTube videos, so students did not freely choose videos based on their own preferences and interests. Finally, this study did not empirically examine the factors influencing learning outcomes, focusing solely on outcomes facilitated by video-based learning. Therefore, it remains unclear whether the observed learning outcomes were directly associated with the use of instructional videos or were influenced by other factors that may have played a more dominant role.

CONCLUSION

This study revealed no significant difference in learning outcomes between students who used instructional videos and those who used YouTube-based videos. In contrast, a statistically significant difference was found in skill-related learning outcomes between the control and experimental groups. These findings suggest that educators should be cautious when selecting YouTube videos, particularly in practice-based learning contexts. While YouTube videos may support cognitive learning, instructional videos appear to be more suitable for facilitating skill development. However, this study is limited by a relatively small sample size, which restricts the generalizability of the findings. Therefore, further research with larger samples and broader contexts is needed to provide more robust evidence for large-scale implementation.

ACKNOWLEDGEMENT

All authors would like to thank Yogyakarta State University for its financial support, which made this research possible. AI (ChatGPT) was used to correct incorrect grammar and inappropriate terminology.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (93-104)
Online: http://journal.uny.ac.id/index.php/jitp

Development of a comic interactive-based problem-based learning model to improve the critical thinking skills of elementary students

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ARTICLE INFO

Article History
Received:
23 September 2025;
Revised:
23 March 2026;
Accepted:
23 March 2026;
Available online:
31 March 2026.

Keywords
Comic interactive;
Critical thinking skills;
Learning models;
Problem-based learning

ABSTRACT

The era of the Industrial Revolution 5.0 requires the education sector to adapt to rapid technological developments, particularly through the adoption of innovative learning models. This study aims to develop a feasible, practical, and effective comic-based interactive Problem-Based Learning (PBL) model to improve elementary school students' critical thinking skills. The method used is research and development (R&D) with the ADDIE model, involving a qualitative approach to assess the product's feasibility and practicality, and a quantitative approach to measure its effectiveness through a pretest-posttest design. The research subjects were 30 fifth-grade students at Elementary School 9 Sila, Bima Regency. The instruments used included a feasibility questionnaire, a practicality questionnaire, and a critical thinking skills test. The results showed that the products developed for the PBL model (90.8%), interactive comics (96.5%), and critical thinking skills tests (95.7%) were feasible for use. The practicality level of interactive comics (93.25%) and critical thinking skills tests (97.75%) was very practical for use in elementary school learning. The n-Gain test results showed an increase in critical thinking skills with an average score of 0.74 (high category). This was supported by a significant paired-samples t-test ($p < 0.05$), which showed a difference between the students' pretest and posttest scores. In general, these results indicate that the application of the comic interactive-based PBL model is effective in improving students' critical thinking skills.

How to cite:
Amrin et.al., (2026). Development of a comic interactive-based problem based learning model to improve the critical thinking skills of elementary students. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 93-104. https://doi.org/10.21831/jitp.v13i1.89880

INTRODUCTION

The rapid development of technology in the era of the Industrial Revolution 5.0 has brought significant changes in various aspects of life, including the world of education. This era is characterised by collaboration among advanced technology, artificial intelligence, and big data (Apriliyanti & M, 2022; Awotunde et al., 2023). As a result, it requires every individual to have adaptive skills to survive in a dynamic environment. Teachers, as the spearhead of education, are required to integrate learning models and media that align with the needs of the times, especially in developing a critical, creative, communicative, and collaborative student profile from elementary school age onward.

The Merdeka Curriculum responds to these needs by emphasising the development of 21st-century skills, including critical thinking. These skills include the ability to analyse information, evaluate arguments, solve problems, and make decisions reflexively (Alsaleh, 2020; Walter, 2024). At the elementary school level, critical thinking skills are very important to instil from an early age because they form the foundation for mastering more complex literacy and numeracy at the next level of education (Dewi & Wardani, 2021; Ramadhani & Setiawan, 2023; Puspita & Parma Dewi, 2021).

The spotlight on the skill achievement of Indonesian students at the international level still reveals a considerable gap. The results of the Programme for International Student Assessment (PISA) survey in 2022 place Indonesia relatively low in reading, science, and mathematics literacy. This fact underscores the need for innovative efforts to improve learning quality, enabling students to develop critical thinking skills and address global challenges. One step is to present a learning model that fosters critical thinking through meaningful learning experiences.

The Problem-Based Learning (PBL) model has been widely recognised as an effective model for fostering critical thinking skills (Ningrum et al., 2024; Setyawan & Koeswanti, 2021). Through the presentation of contextual problems, students are invited to explore information, discuss, find alternative solutions, and independently or collaboratively reach conclusions (Nora et al., 2023; Owens & Hite, 2022). However, previous implementations of PBL in elementary schools still face several obstacles, particularly regarding the availability of learning media that align with the characteristics of digital-generation students. Elementary school students tend to be more interested in visual, interactive media that are closely related to their daily lives (Galada & Baytar, 2025; Hoffmanová et al., 2025; Putri et al., 2025).

Based on this, this research identifies the interactive comic as one of the media with potential for use. This media not only presents an interesting visual narrative but also includes interactive elements that engage students in the learning process (Faradiba & Budiningsih, 2020; Matuk et al., 2021; Prinandari et al., 2024). Several studies have shown that interactive comics can embrace various learning styles, both visual, auditory, and kinesthetic, while embedding educational content in a fun way (Damayanti et al., 2024; Reinita et al., 2023). The latest in this study, the integration of comic interactive into the PBL model, is expected to overcome implementation barriers while increasing student involvement in learning. In line with the following Figure 1, the bibliometric analysis results are shown.

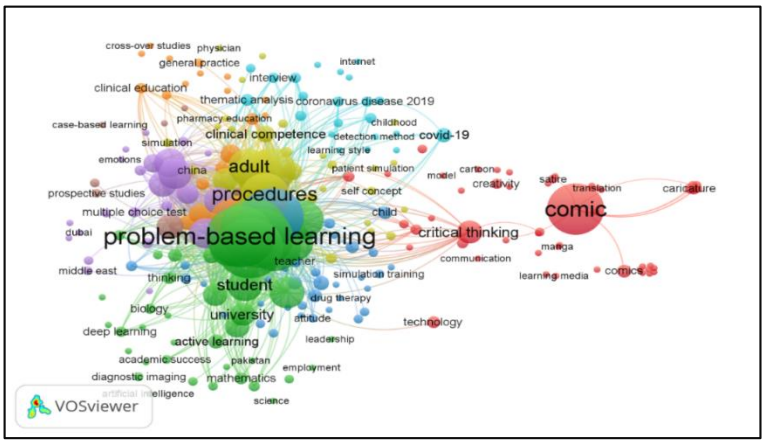

Figure 1. PBL Networking, Critical Thinking, and Comic Trends in Research in the Last 5 Years

Figure 1 shows that the VOSviewer mapping of 357 research articles over the last five years highlights a research gap between the dominance of procedural Problem-Based Learning and the continued positioning of comics as complementary media. The interactive, comic-based PBL model offers a systematic pedagogical integration that stimulates elementary school students' critical thinking in a contextual and meaningful way.

Based on the description above, this research focuses on developing an interactive, comic-based PBL model to improve elementary school students' critical thinking skills. This research is

designed to answer two main problem formulations, namely: (1) What is the feasibility and practicality of the comic interactive-based PBL model in elementary school learning? and (2) How effective is the model in improving students' critical thinking skills? In the end, this research is expected to make theoretical and practical contributions to the development of innovative learning strategies that meet the demands of the Industrial Revolution 5.0 era.

METHOD

This research is of the Research and Development (R&D) type using the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model. The purpose of the research is to improve students' critical thinking skills through the development of an interactive, comic-based PBL that is feasible and practical to use. The research subjects were 30 grade V students from Elementray School 9 Sila, Bima Regency, selected using purposive sampling. The research instruments included a feasibility questionnaire filled out by material experts, media, and test instruments. Next, a practicality questionnaire was completed by teachers and students. Finally, there was a critical thinking skills test based on indicators of reflective attitude, problem-solving, analysis, evaluation, and decision-making. A total of 11 questions on critical thinking skills will undergo validity testing before the test.

The research procedure includes five stages of the ADDIE model. The analysis stage aims to identify students' characteristics and learning needs. More is related to teachers' perceptions of the application of learning with modern models and media, or, generally, to identifying research problems, followed by the design stage, which aims to describe the initial design of the developed learning product. This development product is intended as a solution or follow-up to the results of the previous analysis stage. Next is the development stage, aiming to develop or compile a development product, which is then tested for feasibility validation and empirical validity, followed by the implementation stage of the development products into the research class. The last is the evaluation stage, which assesses the results of applying development products and whether they address the research problems faced.

As a result of the above research procedure, the research will have qualitative and quantitative data. Qualitative data is obtained from product feasibility and practicality validation questionnaires. Qualitative data consist of teachers' perceptions of students' critical thinking skills and the use of modern learning models and media. Qualitative data also consists of expert interpretations of validation scores for the feasibility and practicality of development products. In contrast to quantitative data, it is obtained through empirical validity tests and pretest-posttest scores of students' critical thinking skills.

The results of this qualitative data were analysed in the form of a statement and described in the introduction. In contrast to quantitative data in the form of test scores, validity test scores, question items, and pre- and posttest scores of students' critical thinking skills. This data was analysed using SPSS 24, including n-gain score tests and a one-way ANOVA, to assess the effectiveness of the comic-based interactive PBL model. Then, using the Ministep software (Rasch Model), we can determine the disruption to students' grades.

RESULT AND DISCUSSION

Results

The study's results include three main aspects: product feasibility, practicality, and effectiveness. Previously, a brief description of the product was presented. This research produced an interactive, problem-based learning model product designed specifically for elementary school students. This model follows the PBL syntax, which includes problem orientation through contextual interactive comics, student organisation in understanding problems, independent investigation and analytical activity-based groups, development and presentation of solutions, and analysis and evaluation of problem-solving processes. The integration of interactive comics serves as a visual-narrative lighter, strengthening students' cognitive engagement and critical thinking. Comic

interaction facilitates students' cognitive engagement through narrative, dialogue, and interaction, thereby supporting the analysis, evaluation, and reflection that develop critical thinking skills. The description of the comic products produced is shown in Figure 2.

Figure 2. Examples of Comic Interactive Products Produced

Product Eligibility

Three (3) Experts in materials, media, and test instruments have validated the product before it is applied in class. The results are presented in Table 1.

Table 1. Product Eligibility

Learning Products	Assessment Aspects	Validator Score			Average	Category
		I	II	III		
PBL Model (RPP)	Model Fit				3.67	Worthy
	Compatibility of the model with the learning objectives and the Merdeka curriculum	4	4	3		
	Syntax compatibility	4	4	4		
	Relevance of contextual issues	3	4	3		
	Supporting the development of students' critical thinking skills	3	4	4		
	Material Eligibility					
	Compatibility of the material with the syntax	3	3	4		
	Clarity of material in interactive comics	4	3	3		
	Accuracy of material concepts for elementary school students	4	4	4		
	Material compatibility with KD and CP	4	3	4		
	Solid material with a comic interactive	3	4	4		
Comic Interactive	The attractiveness of media design for elementary school students	4	3	4	3.86	Highly Worth It
	Clarity of media usage indicators	4	4	4		
	Visual quality of media	4	4	4		
	The concept of media can present student interactivity	4	4	4		
	Use of language or sentences that are easy for elementary school students to understand	3	4	4		
Critical Thinking Skills Test	Compatibility with critical thinking indicators	4	4	4	3.83	Highly Worth It
	Measuring the appropriate material on interactive comic media	4	4	3		
	Match the score to the difficulty level of the item	4	4	4		
	Compatibility with the time and materials of elementary school students	3	4	4		

Referring to Table 1, the products developed for the PBL (90.8%), comic interactive (96.5%), and critical thinking skills test (95.7%) have been suitable for use. Critical thinking skills tests were also administered to 30 grade VI students to assess the validity of the 11 questions. The results are shown in Table 2.

Table 2. Results of the Validity Test of the Critical Thinking Skills Test

No.	Table Value (5%)	Calculated r Value	Verdict
1	0.306	0.322	Valid
2		0.365	
3		0.431	
4		0.546	
5		0.352	
6		0.646	
7		0.467	
8		0.336	
9		0.618	
10		0.697	
11		0.688	

All Question items were tested on 30 grade VI students, yielding a table R value of 0.306. The score acquisition (r calculated > 0.306) indicated that all the questions developed were valid and could be used to measure students' critical thinking skills.

Product Practicality

Teacher and student responses to the application of interactive comics and critical thinking skills tests are needed to determine the practicality of the research products used in learning. The results are shown in Table 3.

Table 3. Product Practicality

Learning Products	Observation Aspect	Respondent Score (Teacher)			Average	Category
		I	II	III		
Comic Interactive	Students are interested and motivated in learning	4	4	4	3.73	Very Practical
	Students easily use the media without any mistakes	3	4	4		
	The media looks clear and attractive	4	3	3		
	The learning process is more interactive with these media	4	4	4		
	Students can absorb information well in the media	4	4	3		
		Respondent Score (Student)			**Average**	**Category**
		I	II	III		
Critical Thinking Skills Test	Questions according to the material studied before	4	4	4	3.91	Very Practical
	Question scores according to their difficulty					
	Provision of appropriate processing time					
	Clear and precise question instructions					

The results of the product practice. The literature test (Table 3) shows that comic interaction (93.25%) is highly practical for elementary school students' learning. Likewise, the critical thinking skill test (97.75%) is highly practical for assessing critical thinking skills in elementary school students.

Product Effectiveness

The development product will ultimately be evaluated for its impact on students' critical thinking skills. For each critical thinking skill indicator, results are shown in Figure 3.

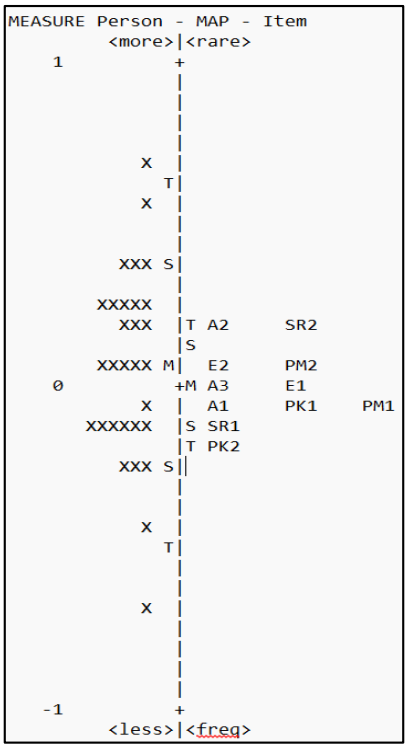

Figure 3. Difficulty Level of Critical Thinking Skills Indicator

Based on Figure 3, the decision-making indicator (PK2) is the easiest for students to answer or achieve. Meanwhile, the analysis indicator (A2) is the most difficult for students to answer or achieve. Unique achievements in reflective attitudes (SR1 and SR2) include relatively moderate question indicators: some students can answer them easily, while others are unable or have difficulty doing so.

The results of the rush analysis of the model above are supported by the n-gain score analysis based on students' pre- and posttest scores for critical thinking skills. The following is presented in Table 4.

Table 4. Pretest and Posttest Results per Indicator

No.	Indicator	Pretest Experiments	Posttest Experiment	N-gain Experiment
1	Reflective Cap	58.50	81.52	0.59
2	Troubleshooting	58.14	84.43	0.67
3	Analysis	58.09	80.35	0.58
4	Evaluation	56.51	80.01	0.60
5	Decision Making	55.89	87.03	0.72

The results of the n-gain score test (Table 4) show that each indicator increased, generally indicating the effectiveness of students' critical thinking skills through the application of development products in the form of interactive, comic-based PBL models. Specifically, the decision-making indicator (PK) is in the high-effectiveness category (72%) due to the application of development products. In contrast, the other four indicators (reflective attitude, problem-solving, analysis, and evaluation) are in the moderate effectiveness category (<70%) due to the implementation of development products.

Furthermore, the achievement curve for the question indicator will be traced for each student to show differences in students' critical thinking skills across indicators. As shown in Figure 4.

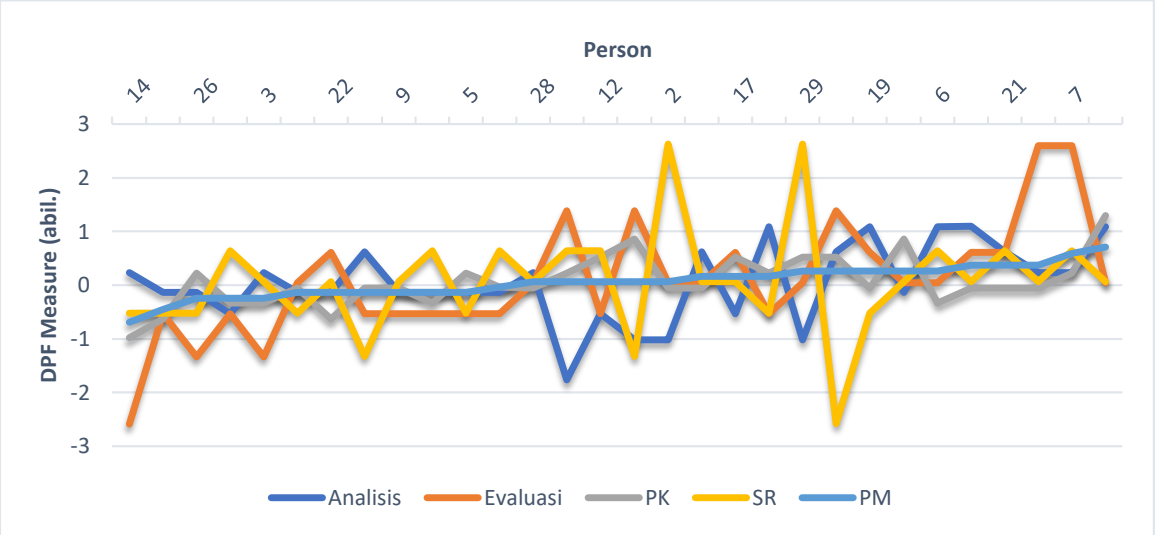

Figure 4. Achievement Curve of Question Indicators

Figure 4 shows that student achievement scores across indicators vary. This achievement indicates that students have different critical thinking skills across the indicators. For example, student number 22 has the highest critical thinking skills on the analysis indicator and the lowest on the reflective attitude indicator. Inversely proportional to student number 29, the maximum on the reflective attitude indicator, and the minimum on the analysis indicator.

When reviewing each indicator, determine whether there is a difference in students' critical thinking skills between pre- and posttest scores. Referring to Table 4, each question indicator has increased, indicating the effectiveness of the interactive comic-based PBL model. It is also necessary to know whether, overall, based on the pre-post test score, there is a difference in students' critical thinking skills. The results are presented in Tables 5 and 6.

Table 5. Results of the Paired Sample Test of Students' Critical Thinking Skills

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Hours of deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Post Test of Critical Thinking Skills - Pre Test of Critical Thinking Skills	4.13333	2.73840	.49996	3.11080	5.15587	8.267	29	.000

The results of the paired-samples t-test (Table 5) showed that there was a difference (sig < 0.05) in students' critical thinking skills scores before (pretest) and after (posttest) learning with the comic-based interactive PBL model.

Table 6. Results of the n-Gain Score Test, Pre-post Test, and Critical Thinking Skills

Pretest (Mean ± SD)	Posttest (Mean ± SD)	N-Gain	Category	
64.20 ± 2.24	92.96 ± 2.85	0.74	Height	The results of the paired-samples t-test (Table 5) showed that there was a difference (sig < 0.05) in students' critical thinking skills scores before (pretest) and after (posttest) learning with the comic-based interactive PBL model.

The results in Table 6 indicate that the comic-based interactive PBL model is highly effective (0.74) in improving students' critical thinking skills.

Discussion

Product Qualification in Theoretical and Research Perspectives

The validation results from material and media experts, with a feasibility score of 91.25%, placed this interactive PBL model in the "very feasible" category. This value indicates that, in terms of content, learning flow, and media quality, the product meets innovative learning quality standards. In the context of learning design theory, this success can be attributed to the consistent application of the ADDIE framework. The analysis stage ensures it is suitable for elementary school students (Haifaturrahmah et al., 2020; Muhammad et al., 2025). Design and Development produces media that is in accordance with Mayer's multimedia learning principles, such as the principles of Kuba et al., (2021) of dual coding (the combination of text and images), coherence (avoiding redundant information), and contiguity (placement of text near visuals).

Empirically, this feasibility achievement is in line with research by Matuk et al., (2021), which confirms that comic-based media can increase student engagement if designed with the cognitive and affective aspects of students in mind. In their study, comic media that feature clear narrative flow, interesting illustrations, and relevance to students' lives have been shown to improve understanding of science concepts at the elementary school level. The products produced in this study adopt a similar strategy, namely, presenting problems in the form of contextual visual narratives.

From a curriculum perspective, this feasibility can also be linked to the expected learning outcomes in the Independent Curriculum. This medium not only channels information but also facilitates students' understanding through interactive learning experiences. As one of the products that integrates PBL and interactive comics, the high feasibility demonstrates that proper instructional design can produce media that is not only visually appealing but also has significant pedagogical power.

Product Practicality and Relevance in a Real Classroom

The product's practicality, as measured by teachers and students at 89.50%, shows that this model is easy to use in the classroom without requiring excessive adaptation. Practicality for teachers lies in the availability of clear user guides and learning syntax, so that the implementation process can run as planned without requiring intensive training. This supports the principle of teacher-friendly innovation, which emphasises the importance of learning innovations that can be integrated into teachers' routines without significantly increasing the workload (Hu & Shen, 2024; Shuhaimi et al., 2025).

For students, the ease of access and navigation in the comic interface provides space for self-directed learning. In line with the theory of self-regulated learning, Students who have control over their learning process will be more motivated and responsible for their achievements. Research by Al-Shaye (2021) also found that digital narrative-based learning media can improve students' emotional and cognitive engagement, as they allow students to set their own learning pace and explore material according to their interests.

The students' positive response to this product also shows that comic-based interactive media can embrace a variety of learning styles. Visual and narrative texts support visual and verbal learners. At the same time, interactive elements stimulate kinesthetic learners. This suitability supports Gardner's theory of multiple intelligences, which emphasises that effective learning requires varied experiences to accommodate differences in students' learning styles (Annamalai et al., 2025).

Product Effectiveness in Improving Critical Thinking Skills

The effectiveness of the comic-based interactive PBL model is evident from the average n-gain value of 0.74 (high category) in the experimental class. This increase indicates a transfer of skills from problem-based learning activities to students' critical thinking skills. Indicators such as analysis and evaluation showed the greatest improvement, indicating that students not only understood the material but also assessed and verified the validity of the information they were dealing with.

Theoretically, these findings are consistent with the constructivist learning framework, which positions students as active subjects in the construction of knowledge (Azzahra et al., 2025;

O'Connor, 2022). PBL facilitates the process by directing students to explore problems, formulate hypotheses, seek information, and test solutions. Research from Setyawan & Koeswanti (2021) in elementary school students also showed that PBL significantly improved critical thinking skills, especially when combined with supporting media that motivated students to be actively involved.

Another source of support comes from the results of a one-way ANOVA, which show significant differences between the experimental and control classes, reinforcing the argument that the improvement in critical thinking skills is not the result of chance or external factors but a direct effect of the application of this model. This is in line with the findings Palvia et al., (2023) which states that the integration of problem-solving skills in learning has a causal effect on the improvement of critical thinking skills, especially on indicators of logical analysis and decision making.

Integration with the Independent Curriculum and 21st Century Skills

The comic-based interactive PBL model developed is highly relevant to the implementation of the Independent Curriculum, which focuses on in-depth, meaningful, mindful, and joyful learning. The meaningful learning aspect is achieved because students are faced with real problems in their lives, so the material learned becomes relevant and easy to remember.

In terms of mindful learning, this medium provides students with the opportunity to reflect on every decision taken during the problem-solving process. Visual narratives in interactive comics present scenarios that encourage students to consider the consequences of each action, aligning with the critical thinking indicators of "reflective attitude" and "decision-making". This approach aligns with Dewey's theory of reflective thinking, which holds that effective learning occurs when students relate new knowledge to their experiences through reflection.

The joyful learning component is evident in students' responses, who feel that learning becomes more interesting and less boring. Visual and interactive elements create a learning atmosphere that resembles an educational game, which can lower psychological barriers to learning (e.g., learning anxiety) and increase intrinsic motivation. These findings are consistent with the results of the study by Reinita et al., (2023), which states that digital comics in PBL can increase learning motivation through increased student engagement.

Theoretical and Practical Implications

Theoretically, this research contributes to the literature on 21st-century learning innovations, particularly by integrating PBL models with interactive digital media. The resulting product demonstrates that combining problem-based pedagogical strategies with learning technology can lead to significant improvements in critical thinking skills (Maquiling & Desabella, 2025; Pavitola & Rieksta, 2025). This model can serve as a reference for developing other learning media focused on higher-order thinking skills (HOTS).

In practice, this model has great potential for widespread implementation in elementary schools, especially in areas that have adopted the Independent Curriculum. Teachers can adapt interactive comic content according to other subjects such as science, social studies, or Indonesian (Pramulia et al., 2025; Rajan & Wei, 2025). The product's practicality makes it easy for teachers to integrate into the lesson plan without complicated training, while students can use it independently outside formal lesson hours.

In addition, given that critical thinking skills are among the core competencies outlined in the vision of a Golden Indonesia 2045, the application of this model directly contributes to achieving national education goals. With further development, comic interactive can also be integrated with gamification or augmented reality features to improve interactivity and learning effectiveness.

CONCLUSION

The resulting development products are the comic interactive PBL model and the critical thinking skills test, which have been suitable for use. After implementation, the comic-based interactive PBL model and the critical thinking skills test are highly practical for assessing elementary school students' critical thinking skills. The application of development products can improve students' critical thinking skills. Specifically, the decision-making indicators (PK) are in the

high-effectiveness category due to this application. In contrast, the other four indicators (reflective attitude (SR), problem solving (PM), analysis (A), and evaluation (E)) are in the medium effectiveness category due to the application of development products. In general, there are differences in students' critical thinking skills before and after applying the PBL model through comic interaction. The test-n-gain score shows an increase in students' critical thinking skills, placing them in the high category.

ACKNOWLEDGMENTS

Thank you to the Ministry of Higher Education, Science, and Technology (Kemdiktisaintek) for the Bima grant program in 2025, which enabled the authors and members to carry out research and publish the results of this research. Thank you are also conveyed to the STKIP Taman Siswa Bima campus, the origin campus that provides space for participation in the Bima grant program of the Ministry of Higher Education, as well as for this research permit. Finally, thank you to Elementary School 9 Sila as a place for research, for teachers, students, and school leaders, as well as for those who support and help during the research process.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (105-116)
Online: http://journal.uny.ac.id/index.php/jitp

Integration of 3D objects in an augmented reality flashcard game as an innovation in cognitive learning media at Salafiyah Comal Kindergarten

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ARTICLE INFO

Article History
Received:
23 January 2026;
Revised:
21 March 2026;
Accepted:
21 March 2026;
Available online:
31 March 2026.

Keywords
Augmented reality;
Cognitive abilities;
Flashcard

ABSTRACT

Learning at Salafiyah Comal Kindergarten is still dominated by conventional media, which provide limited visual stimulation and direct interaction, resulting in suboptimal child engagement. Although augmented reality has the potential to enhance interactivity, the development of AR flashcard media integrated with 3D objects and interactive quizzes for early childhood remains limited. Therefore, this study aims to develop an AR-based flashcard game media with a "transportation" theme and to test its feasibility among children aged 4–5 years. The method used is Research and Development (R&D) following the ADDIE model, involving 16 children. The media was developed using Assembler Edu with the integration of flashcards, 3D objects, and interactive quizzes. Validation results showed the media had an 80% feasibility rating in the "Good" category, and the content received a 95.5% rating in the "Very Good" category. Additionally, the media implementation received a 92.75% response rate in the "Very Good" category. These three assessments indicate that the media possesses a sufficiently high level of feasibility and is suitable for practical use as an interactive learning tool to support children's engagement in the learning process. The application of AR showed that children were more active, interested, and engaged in the learning process. Therefore, the developed media is suitable for use as an interactive learning medium to support engagement and cognitive stimulation. Further research is recommended to test the media's effectiveness in enhancing cognitive development using a broader experimental design and a larger sample size.

How to cite:
Azizah, K. A., et al., (2026). Integration of 3D objects in an augmented reality flashcard game as an innovation in cognitive learning media at Salafiyah Comal Kindergarten. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 105-116. https://doi.org/10.21831/jitp.v13i1.93231

INTRODUCTION

The rapid advancement of technology in today's digital age has had a significant impact across various fields, including education. Technological developments have driven innovation in the learning process, aiming to improve the quality and effectiveness of learning. One way technology is utilised in education is through digital media, which can create a more engaging, interactive, and enjoyable learning environment for students. One such technology, currently widely adopted in education, is augmented reality. According to Elvina et al., (2024), AR is a technology that combines

elements of the real world with the digital world, thereby enabling the display of objects more realistically. Objects displayed in AR can range from text and animations to 3D models (Amalia et al., 2024). Three-dimensional (3D) representations of objects with length, width, and height convey a sense of real-world space and depth, allowing users to view them from various angles (Wahyudi et al., 2025). With 3D visualisation in AR, this technology can provide a more interactive learning experience and encourage children's active engagement in the learning process, thereby conveying the material more easily.

As educational technology advances, AR is no longer merely a visualisation tool; it has evolved into an interactive learning medium that integrates animations, 3D objects, and assessment tools such as digital quizzes. The existence of such learning media indicates that AR is increasingly used in early childhood education to optimise children's developmental skills, enhance engagement, and support exploration-based learning experiences (Aydoğdu, 2021). Previous research also shows that the use of AR in early childhood education can improve learning engagement and memory retention. Furthermore, the use of game-based AR can boost children's learning motivation (Muti et al., 2024). This indicates that AR is a key innovation in technology-based learning.

In early childhood education, the use of learning materials plays a significant role in supporting children's optimal development. One of the most commonly used tools is the flashcard. A flashcard is a small card containing text, images, symbols, and captions (Hayati, 2022). This tool offers advantages such as ease of use, practicality, and the ability to enhance children's memory (Yusuf et al., 2021). However, conventional flashcards are generally static and do not provide an interactive learning experience. Therefore, the development of augmented reality-based flashcards is an innovation that can provide a more engaging learning experience by displaying three-dimensional objects and enabling direct interaction through digital devices.

In recent developments, AR-based flashcard media has also begun to be developed using a game-based learning approach (Yu et al., 2022), allowing children to interact through quizzes and receive immediate, active feedback. This indicates that the integration of AR and flashcards is increasingly geared toward more participatory learning, focusing not only on concept recognition but also on children's active engagement in the learning process. Such active engagement is crucial, as it is closely linked to children's cognitive development, specifically their ability to think, understand, and solve problems (Ramlah et al., 2022), and it also impacts their lives both now and in the future (Dewi et al., 2023). Therefore, it is necessary to provide appropriate stimulation through meaningful learning tailored to young children's characteristics.

Early childhood, defined as the age range of 0–6 years (Putri & Lili, 2021), is known as the "golden age", a period marked by rapid development across various aspects (Uswatun & Nur, 2022). During this period, children learn through direct experience, observation, and imitation (Nurfadilah & Miftakhul, 2021), thus requiring learning media that provide concrete, interactive experiences. Theoretically, this can be explained through constructivism, which states that knowledge is actively constructed through experience. Additionally, the "learning by doing" theory emphasises that learning is more effective and the experience is more active and meaningful when children are directly involved in the learning process (Astprachon et al., 2025). In this context, AR becomes relevant because it can provide visual-based learning experiences and direct interaction. According to multimedia learning theory, the combination of text, visuals, and interaction in AR can enhance information processing by providing stimuli through multiple cognitive channels simultaneously. This is further supported by Piaget's cognitive development theory, which explains that young children are in the preoperational stage, a stage requiring concrete media to understand concepts that are still abstract (Anggrian & Saefurahma, 2025). Therefore, integrating AR into flashcards is a solution because it can visualise concepts in a tangible, interactive way.

Based on observations and interviews at Salafiyah Kindergarten, the learning process remains dominated by conventional methods, such as lectures, reading activities, and the use of pictures as learning media. This situation results in children lacking direct and contextual learning experiences (Cahyaningtyas, 2020). Additionally, the use of technology-based learning media remains limited, resulting in suboptimal learning processes and low student engagement (Atikah et al., 2023). Based on previous research, AR has been proven to enhance children's engagement and understanding. However, most studies have focused on visualising 3D objects without integrating evaluative

activities such as interactive quizzes. Furthermore, existing AR-based flashcards still primarily serve as tools for concept introduction and have not yet been fully developed into comprehensive interactive learning media. Research conducted by Ramlah et al., (2023) indicates that young children still face challenges in recognizing letter and number symbols. Salam & Ramadhan (2025) indicate that AR media is more effective than conventional visual media because it presents objects realistically. Elvina et al., (2024) also state that AR-based flashcards are more engaging due to their interactive nature. Based on this synthesis, there remains a gap between the learning needs of young children, which are interactive, concrete, and participatory and the currently available media, which are still limited to visualisation. Therefore, there is a need to develop learning media that integrates 3D objects, active interaction, and learning assessment into a single, comprehensive system.

This study aims to develop an augmented reality-based flashcard game that can interactively display 3D objects and includes a quiz feature for learning assessment. The primary focus of this study is to create interactive, engaging learning media tailored to young children's characteristics to support the development of their cognitive abilities. The contributions of this study encompass both theoretical and practical aspects. Theoretically, this study is expected to expand the body of research on the development of AR-based learning media that integrates visualisation, interactivity, and evaluation into a single medium. Practically, this study is expected to serve as an innovative and meaningful alternative learning medium, capable of optimally enhancing children’s engagement and cognitive development.

METHOD

This study employs the Research and Development (R&D) method to develop a new product and validate its effectiveness in the product development process. The development model used in this study is ADDIE; the development process is carried out through several stages: Analysis, Design, Development, Implementation, and Evaluation (Karmila, 2024). This study uses an R&D design with a descriptive-evaluative approach, namely, product development focused on the validation and feasibility testing of the media, and implementation testing conducted as a one-shot to identify user responses to the developed media (Adzani & Pramuditya, 2025).

This study involved kindergarten B teachers and students as research subjects, specifically 4 (four) teachers and 16 kindergarten B students at Salafiyah Sidorejo Comal. The subject selection technique used total sampling, in which the entire population served as the research subjects, as the sample size was relatively small and all were involved in the media implementation process (Hakiki et al., 2022). This study collected qualitative and quantitative data from 16 children in Group B at Salafiyah Sidorejo Comal Kindergarten. The stages of the ADDIE model used in this study are as follows:

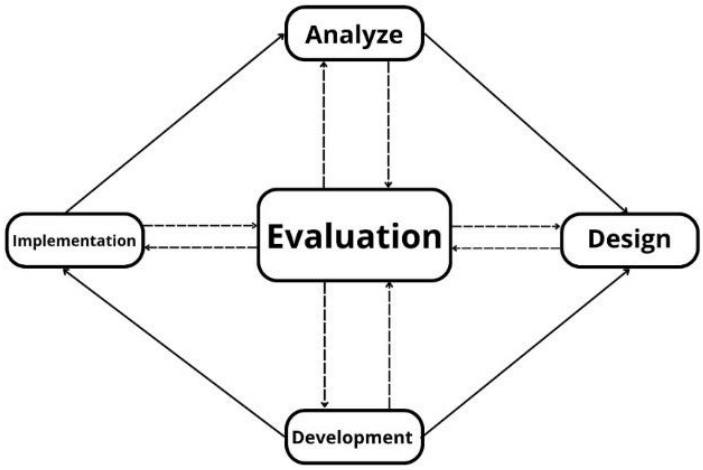

Figure 1. The ADDIE Model

Analysis

The Analysis phase aims to identify the needs and challenges faced by teachers and students at Salafiyah Sidorejo Comal Kindergarten so that the educational media developed can create a more engaging learning experience and support the improvement of young children's cognitive abilities. (Permana et al., 2023). This stage involves observing the learning process, conducting interviews with classroom teachers, and collecting data from the outset (Khoirunnisa et al., 2024) to obtain a comprehensive picture of the challenges faced. The results of this analysis are then used as a foundation for designing teaching materials that align with the needs of young children.

Design

In the Design phase, the researcher developed instructional materials and learning pathways by establishing learning objectives, designing scenarios, conceptualising the product, determining the Augmented Reality (AR) design, and planning the evaluation of the instructional media (Rachma et al., 2023). In this stage, the design of flashcard-based learning media was also carried out using an AR application supported by Sketchfab 3D and Canva for visual processing and customisation. This stage included creating flashcard designs, selecting 3D images as needed, and editing them in Assembler Edu to display the objects in 3D.

In addition, during the research design phase, a questionnaire was developed to facilitate the creation of AR-based flashcard learning materials. This questionnaire served as a tool for collecting data throughout the field research. The questionnaire instruments included evaluation forms for media and subject matter experts, as well as a survey to gather teacher feedback. The feedback provided by these experts was used to ensure that the developed teaching media aligned with the intended instructional objectives.

Instrument validation was conducted to ensure that the questionnaire could measure aspects relevant to the research objectives. Media experts and subject matter experts conducted the validity test. The experts evaluated each statement against the indicators. The results of this evaluation were used as the basis for revising the instrument until it was deemed suitable for use in the research.

Development

In this stage, the researcher develops a prototype or educational media aligned with the initial plan established during the design phase (Wibowo et al., 2022). The development stage is where the researcher creates AR-based flashcards using the Assembler Edu app and other supporting tools, such as Sketchfab 3D and Canva, then prints them for easy implementation. The initial product developed first undergoes validation by experts, such as media specialists and subject matter experts. Next, the feedback from these experts is used to revise the media before it is tested with students. Subsequently, the researcher collects data through a questionnaire to observe the children's responses to the implemented media and the classroom teachers at Salafiyah Sidorejo Comal Kindergarten.

The questionnaire data will be analysed using a Likert scale, as shown in Table 1, with the following categories: invalid, less valid, somewhat valid, valid, and very valid:

Table 1. Likert Scale

No.	Category	Range
1	Invalid	1
2	Less Valid	2
3	Fairly Valid	3
4	Valid	4
5	Very Valid	5

The researchers then conducted a validation test using a questionnaire based on expert validation by media and material experts, as well as post-implementation validation by classroom teachers. Once the scScores were obtained, they were calculated using quantitative data to determine a rating scale expressed as a percentage. The calculation used the following Formula 1 (Setiawan & Rahman, 2025).

$$P = \frac{\Sigma R}{N} \times 100\% \quad (1)$$

Information:
P = Percentage of the score being calculated
$\sum R$ = Total answers provided by the validator
N = Maximum total score obtained

Once the percentage of the score is obtained, it can be converted to enable the researcher to determine whether the learning media is valid. The categories of invalid, less valid, moderately valid, valid, and highly valid can be seen in Table 2 under the score percentage category.

Table 2. Score Categories and Percentage

No.	Category	Score Range
1	Excellent	81% - 100%
2	Good	61% - 80%
3	Fair	41% - 60%
4	Poor	21% - 40%
4	Veri Low	0% - 20%

(Nurhidayah et al., 2024)

Implementation

The next developed product entered the implementation phase. In this phase, the researchers implemented the augmented reality-based flashcard media, which had been revised in accordance with feedback and notes from media experts and subject matter experts (Insani & Firdaus, 2024). Both experts confirmed that the media was suitable for use, enabling the implementation of the flashcard media. This implementation phase involves testing the flashcard product on 16 preschool-aged children at Salafiyah Sidorejo Comal Kindergarten.

Evaluation

The evaluation phase was conducted to assess the suitability of the AR-based flashcard game media developed (Elvina et al., 2024). To determine the effectiveness of the flashcard media, evaluation is necessary, whether formative or summative (Siregar et al., 2022). Formative evaluation is an evaluation conducted throughout the media design and development process. Meanwhile, summative evaluation is conducted after the media has been implemented, specifically through an analysis of teachers' and children's responses to the media (Wardani et al., 2022).

In this analysis plan, the researcher developed a questionnaire for validation by media and subject matter experts. Subsequently, the questionnaire data were analysed to evaluate the quality of each instrument item. In addition, reliability tests were conducted to determine the instrument's consistency in generating data when used repeatedly.

RESULT AND DISCUSSION

Results

This study produced an educational tool in the form of an augmented reality-based flashcard game, developed using quantitative methods involving a questionnaire and a pilot implementation at Salafiyah Sidorejo Comal Kindergarten. The results of the quantitative methods and the stages of development are as follows.

During the analysis phase, the researcher conducted observations and interviews with the teacher of Class B. The results of these observations and interviews indicated that instruction still relied on conventional methods, such as lectures supplemented by books and pictures, leaving children with limited opportunities for direct, interactive learning experiences. Meanwhile, the characteristics of less competitive, highly curious children indicate a need for more interactive media.

These findings reveal a gap between the active and exploratory learning characteristics of young children and a teaching approach that remains largely passive. Therefore, an AR-based flashcard game was developed as an alternative solution to provide students with a more concrete and interactive learning experience.

Next, during the design phase, the educational material was developed as 12 × 8 cm flashcards containing two main activities: introducing modes of transportation through AR-based 3D object visualisation. In this game, children will be introduced to various modes of transportation and their components through 3D AR displays that appear when a barcode is scanned, along with interactive quizzes with immediate feedback. When a child selects an answer, the system provides immediate feedback: a happy icon appears if the answer is correct, and a crying icon appears if it is incorrect. Thus, from a pedagogical perspective, this design serves not only as a medium for delivering content but also as a tool that supports cognitive stimulation by integrating visualisation, interaction, and reinforcement of children's learning responses.

The learning media developed is an AR-based flashcard game. The flashcard game was created through a combination of manual methods and technology, while the AR was created using the Assembler Edu, Sketchfab, and AR applications. The images used in the flashcard creation process are shown in Figure 1 below. In this digital medium, the researcher used the Assembler Edu app. This app can be downloaded from the Google Play Store and used on smartphones and tablets as needed; it can be seen in Figure 2 below.

Figure 1. Flashcard

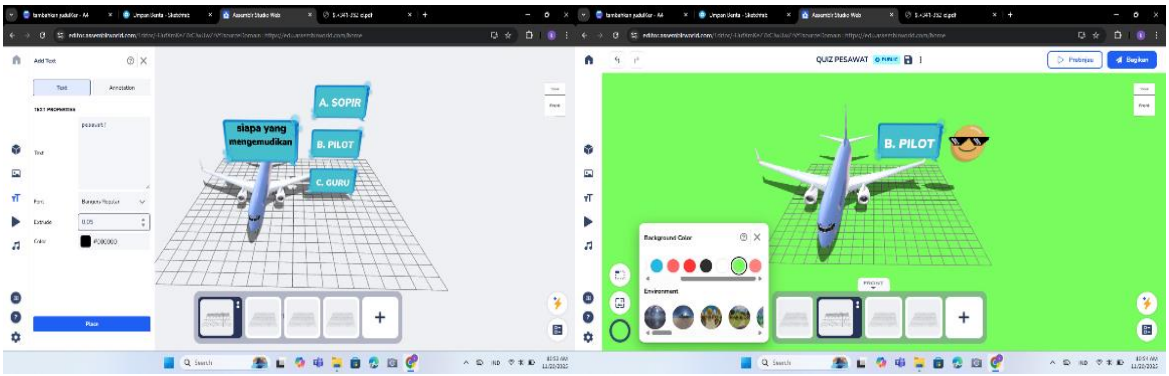

Figure 2. Editing Process with Assembler Edu

After the media was developed, the next step was to conduct validation by media experts and subject matter experts. The validation process was carried out by completing questionnaires and by the experts providing comments and suggestions for improvement. The validation results from the media and subject matter experts are shown in Tables 3 and 4. The following presents the assessment results from both experts.

Table 3. Media Validation Result

No.	Indicator	Percentage
1	Design Aspects	80%
2	Media Feasibility Aspects	73.3%
3	Software Usage Aspects	80%
Total		**80%**

Table 4. Material Validation Result

No.	Indicator	Percentage
1	Material Feasibility Aspect	96%
2	Presentation Feasibility Aspect	95%
3	Grammar Aspects	86.6%
Total		**95.5%**

Based on the media expert validation result of 80%, the assessment result for the media falls into the "Good" category. In comparison, the content expert validation achieved 95.5% in the "Very Good" category, indicating that the learning materials align with the needs and characteristics of early childhood. Based on these results, the researcher conducted the learning activity using AR-based flashcards. During the learning phase, children are introduced to various types of transportation through flashcards displaying 3D vehicle images and learn about the parts of the vehicles. This process aims to help children understand the concept of transportation more concretely through interactive digital visualisation. After the children have become familiar with transportation and its parts, the activity continues with an interactive quiz. This quiz appears when scanning the barcode on the flashcard, displaying simple questions appropriate for the children's abilities. The children are then asked to select the correct answer from the available options. This activity helps children reinforce their understanding of the learned material through an Augmented Reality-based learning experience.

Figure 3. Flashcard Implementation

Table 5. Results of the Flashcard Implementation Questionnaire

No.	Indicator	Percentage
1	Feasibility Aspects	96%
2	Language Feadibility Aspects	85%
3	Grammar Aspects	100%
4	Media Suitability Aspects	90%
Total		**92.75%**

During the implementation phase, the AR-based flashcard learning media must undergo an evaluation process. The purpose of this evaluation is to improve the quality of the final product by incorporating classroom teachers' comments and suggestions for improvement from the implementation phase in Class B. In this study, the evaluation process was conducted by referring to assessment results and recommendations from media and content experts (validators), which were then conveyed to teachers as feedback on the developed media. These assessments serve as a crucial reference for evaluating and refining the AR-based flashcard game learning media for development in subsequent stages. The survey results from the implementation obtained during the evaluation phase showed a score of 92.75%, which falls into the "Very Good" category. These results indicate that the developed media demonstrates high quality and strong user acceptance and engagement. However, these results primarily reflect users' responses and perceptions of the media, and thus do not directly indicate an improvement in children's cognitive abilities.

Discussion

The development of augmented reality-based flashcard games in this study demonstrates that the presence of technology does not solely determine learning effectiveness, but rather how that technology is integrated into an interactive and meaningful instructional design. This indicates that AR serves as a learning aid. At the same time, the primary factors influencing cognitive improvement are the combination of concrete visualisation, exploratory activities, and the immediate feedback children receive during the learning process.

Stimulating cognitive development in early childhood requires access to interactive learning resources. In this regard, AR-based learning media have the potential to increase children's engagement through their visual and interactive characteristics. This is supported by research conducted by Amalia et al., (2024), which states that the use of AR in early childhood education contributes to the improvement of children's cognitive capacity and intellectual development by presenting more concrete learning experiences, thereby making it easier for children to understand and remember complex concepts. In this context, this study offers an additional contribution by integrating evaluation elements into the medium; thus, the function of flashcards is not limited to serving as a mere introduction to concepts. Rather, they also serve as a tool for reinforcing understanding. Critically, this indicates a shift from using AR as a representational medium to an interactive learning system, enabling a more active and reflective learning process.

Previous research by Anggreani & Satrio (2021) found that using AR flashcards with animal identification concepts helps children recognise objects more accurately. In this context, this study adds value by integrating evaluation elements into the media; it does not merely focus on visualisation but also incorporates interactive evaluation elements, thereby making the learning process more comprehensive. Thus, this educational media is designed with the primary objective of maximising young children's cognitive abilities. The presentation of the material is supplemented with visual support in the form of text and 3D object displays, along with their explanations, as well as simple quizzes designed to assess and reinforce children's understanding of the learned material. This aligns with the view that children's understanding can develop when using learning media that is effectively structured and aligned with children's developmental characteristics (Atikah et al., 2023).

Learning using Augmented Reality can influence collaborative learning Kuanbayeva et al., (2024) because the learning mechanism in this medium can be observed through the interactions that occur when children use AR flashcards together. When children scan the flashcards and answer interactive quizzes, a "correct" or "incorrect" response appears, which can trigger spontaneous discussions among them, such as asking questions, comparing answers, and helping peers who have not yet grasped the material. In this process, AR flashcards serve as a learning stimulus that encourages social interaction, so that learning does not only occur between the child and the medium but also evolves into a collaborative process among students. Thus, the use of this medium not only enhances individual learning experiences but also strengthens social learning in the classroom.

Faculty members specialising in educational media and materials conducted a validation of the developed product. The validation results showed that the product received a feasibility score of 80% ("Good") and 95.5% ("Very Good"). These results indicate that the developed media meet the

feasibility criteria for implementation in early childhood education. Thus, the development of AR-based learning media is projected to improve children's cognitive abilities through more interactive and engaging learning presentations. Additionally, implementing this media can create a more conducive learning environment and provide enjoyable learning experiences that optimally support children's developmental and growth processes. These findings align with Nasution et al., (2022), which states that AR can help enhance learning by integrating the real and virtual worlds, making the material easier to understand. In this study, AR was used not only to view 3D images but also combined with flashcard quizzes to encourage students to be more active during learning. Furthermore, research conducted by Elvina et al., (2024) indicates that the use of AR can overcome the limitations of the availability of real objects in the learning process. These findings are relevant to the research site, which is still dominated by conventional learning media. However, this study demonstrates that the success of AR is not solely due to its visuals but also because of its usage method, which actively engages children through interaction and quizzes.

To support early childhood development, teaching media that capture attention and provide interactive learning experiences are needed. The Assembler Edu application is one technology that can be utilised to create innovative and engaging teaching tools (Elvina et al., 2024). Through Assembler Edu, AR-based flashcard games can virtually visualise real-world objects, thereby facilitating teachers in explaining the material. In this study, Assembler Edu was used to develop an AR application that introduces various types of transportation, explains their components, and provides simple quizzes that children can answer through a flashcard game.

This study has several limitations, particularly regarding the sample size, which consisted of students from only one class, and the relatively short duration of the study; consequently, the results obtained may not yet represent broader conditions. Furthermore, this study remains focused on cognitive aspects and has not yet explored the impact of AR-based media on other areas of development. Therefore, further research is needed that involves a broader range of subjects, a longer implementation period, and the use of more comprehensive evaluation indicators to produce findings that are more representative and more accurate.

CONCLUSION

This study aimed to develop an augmented reality-based flashcard learning medium using the ADDIE model for early childhood students at TK Salafiyah Sidorejo Comal. Validation results indicated that the developed medium falls into the "good" category, with 80% from the media expert and 95.5% from the content expert, placing it in the "very good" category. These findings indicate that integrating 3D visualisation via AR can support the recognition of basic concepts, such as letters and numbers, in early childhood learning, particularly by enhancing the appeal of learning media. However, it cannot yet be concluded that the limitations of this study lie in the scope of implementation, which remains limited—both in terms of the number of subjects and the context of use—so the results cannot yet be widely generalised and have not empirically measured the media's impact on aspects of child development. Scientifically, this study contributes to the development of AR-based educational media design by integrating flashcards with 3D visualisation as an interactive media innovation in early childhood education, particularly in educational product development. Therefore, future research is recommended to conduct an effectiveness test using an experimental design with a control group, involving a broader and more diverse range of subjects, and measuring the measurable impact of media use on aspects of child development, such as the ability to recognise letters and numbers, social interaction during learning, and motor skills in the use of augmented reality-based media.

ACKNOWLEDGEMENTS

The author would like to thank his supervisor for his guidance, feedback, and encouragement, which enabled him to complete this journal article.

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Jurnal Inovasi Teknologi Pendidikan
Volume 13, No. 1, March 2026 (117-131)
Online: http://journal.uny.ac.id/index.php/jitp

Development of microlearning media science concepts in senior high school: Emphasis on technology literacy

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ARTICLE INFO

Article History
Received:
3 January 2026;
Revised:
27 March 2026;
Accepted:
28 March 2026;
Available online:
31 March 2026.

Keywords
Microlearning media;
Secondary school;
Science concept;
Technology literacy

ABSTRACT

Science learning in secondary schools often struggles to explain abstract concepts such as biological mechanisms and cellular processes, which are difficult for students to visualise using conventional teaching methods. This condition contributes to low conceptual understanding and limited technological literacy among students. To address this issue, this study developed science microlearning media designed in short, interactive, and focused learning units. This study aimed to identify the characteristics of science learning in secondary schools, determine the validity of the developed microlearning media, and examine their effectiveness in improving students' conceptual understanding and technological literacy. The study employed a research-and-development method that included needs analysis, product development, expert validation, and feasibility testing. The validation results showed that the developed media achieved a very high validity score, with a content score of 4.52. Feasibility assessments also demonstrated high acceptance with average scores of 4.47 and 4.51, respectively. These findings indicate that the developed microlearning media are feasible and have strong potential to support science learning, particularly in facilitating students' understanding of abstract concepts. Future studies are recommended to conduct broader experimental investigations and integrate advanced technologies to enhance the scalability and effectiveness of microlearning media.

How to cite:
Marlina, R., Hamdani & Pamungkas, R. (2026). Development of microlearning media science concepts in senior high school: Emphasis on technology literacy. *Jurnal Inovasi Teknologi Pendidikan, 13*(1), 117-131. https://doi.org/10.21831/jitp.v13i1.94536

INTRODUCTION

Science learning in secondary schools demands an understanding of abstract and complex concepts, often not directly observable, such as atomic structure and molecular phenomena beyond everyday experience (Aleknavičiūtė et al., 2023). Conceptual understanding is a major challenge because students often bring inappropriate prior knowledge or misconceptions that need to be restructurd through deeper learning processes (Aleknavičiūtė et al., 2023; Soeharto et al., 2019). Research in the science education literature indicates that addressing complex concepts with lectures and traditional statistical media alone is often ineffective in fostering profound conceptual change and addressing students' misconceptions (Addido et al., 2022). These findings align with those of a

systematic review, which shows that identifying misconceptions is a crucial step in fostering conceptual change and meaningful science learning, as misconceptions tend to persist without appropriate intervention and hinder accurate scientific understanding (Guerra-Reyes et al., 2024). The characteristics of today's high school students indicate that they belong to a generation that is very familiar with digital technology in their daily lives, but their technological literacy has not yet developed optimally in the context of formal learning, especially in science learning (Laius & Orgusaar, 2025; Mat et al., 2024). Technological literacy not only includes the technical ability to operate digital devices but also includes critical thinking skills in understanding, comprehending, processing, and utilising digital information to build accurate and meaningful scientific knowledge. Recent research confirms that students' digital literacy competencies are an important factor, including science process skills such as data collection, interpretation of results, and the ability to draw critical conclusions about scientific phenomena (Astalini et al., 2023).

However, despite the increasing prevalence of technology in science classrooms, the pedagogical integration of digital media is often hampered by limited teacher preparedness, limited learning infrastructure, and curricula that do not fully support optimal technology use (Apriyanto, 2025; Laius & Orgusaar, 2025). The lack of a systematic approach to technology integration means students' opportunities to use technology as a tool for critical and exploratory thinking have not been fully realised (Son & Ha, 2024). Higher technological literacy enables students to evaluate digital information sources, use interactive simulations to build mental models of science, and connect science concepts with real-world phenomena more effectively. Furthermore, educational literature indicates that science learning that does not consistently incorporate pedagogical digital media, such as simulations, virtual laboratories, interactive platforms, and data science software, may underutilise students' potential for technological literacy development (Apriyanto, 2025). This, in turn, has an impact on students' low ability to think critically and creatively in a scientific context, even though these two skills are important components of 21st-century technological literacy.

Technological literacy has become a central component of contemporary education, encompassing competencies beyond basic technical skills. This includes the ability to access, evaluate, interpret, and apply digital information effectively and ethically (van Laar et al., 2019). International frameworks such as DigCompEdu and UNESCO's Global Framework for Digital Literacy emphasise that technological literacy is essential for lifelong learning and active participation in a knowledge-based society (Ghomi & Redecker, 2019; Law et al., 2018). In science education, technological literacy is crucial because scientific knowledge is increasingly represented and communicated through digital media (Okra, 2023). Students are expected to interpret data visualisations, simulations, and digital models and evaluate the credibility of online scientific information. Research shows that although secondary school students frequently use digital devices, their technological literacy often remains at a functional level, focusing on information access rather than critical analysis and application (Antonietti et al., 2025; Oktasari et al., 2025).

Empirical studies have shown that integrating technological literacy into subject-specific instruction leads to improved learning outcomes and higher-order thinking skills (Sung et al., 2016). In science education, technological literacy supports inquiry-based learning, data analysis, and problem-solving, which are core components of scientific practice. Microlearning media offer structured opportunities to embed technological literacy skills into science learning activities by requiring students to interact with digital representations, evaluate information sources, and reflect on their learning process.

The integration of microlearning and technological literacy is a strategic approach to addressing conceptual and skill-based learning objectives in science education. Microlearning environments inherently rely on digital platforms, making them well-suited for embedding components of technological literacy. Research shows that microlearning modules designed with interactive elements and reflective tasks can simultaneously support conceptual understanding and the development of technological literacy (Sung et al., 2016). From a constructivist perspective, learning occurs through active engagement and interaction with content and tools (Escobar-Castillejos et al., 2024). Microlearning media that encourage exploration, experimentation, and reflection align with constructivist principles and support meaningful learning. Furthermore, microlearning facilitates self-directed learning by allowing students to control the pace, sequence,

and repetition of learning activities, which are key aspects of technology-mediated learning environments. Despite its potential, experts caution that microlearning must be carefully designed to avoid knowledge fragmentation (Boulton & Cobb, 2017). Effective integration requires a coherent sequence of micro-units and explicit connections between concepts. When these conditions are met, microlearning can increase conceptual depth while encouraging critical and reflective use of technology.

Although existing research highlights the potential benefits of microlearning and technological literacy in education (Antonietti et al., 2025; Oktasari et al., 2025), several gaps remain. First, most empirical research on microlearning has focused on higher education and professional training contexts, with limited attention to secondary school science education. Second, studies often examine the effectiveness of microlearning in terms of engagement or achievement without explicitly addressing technological literacy outcomes. Furthermore, there is a lack of comprehensive research integrating microlearning design principles with established technological literacy frameworks in science education. Many studies use microlearning as a delivery strategy without systematically embedding technological literacy goals into the instructional design. This gap underscores the need for research examining how microlearning media can be intentionally designed to support conceptual understanding and the development of technological literacy in secondary school science classrooms. Addressing this gap is crucial for advancing pedagogical innovation and informing evidence-based instructional design.

Given these conditions, developing micro-learning media for science concepts in secondary schools is both relevant and strategic. This development is not only aimed at improving students' conceptual understanding of science materials, but also at equipping them with functional, critical, and contextual technological literacy. Through structured, interactive, and technology-based learning experiences, micro-learning media can bridge the demands of the 21st-century curriculum with classroom practices, while strengthening students' readiness to face the challenges of learning and life in the digital era. There are 3 problems in this study, namely: a) What are the characteristics of secondary school science learning in the development of micro-learning media based on technological literacy (RM 1)? b) What is the level of validity of the micro-learning media developed for learning science concepts (RM 2)? and c) What is the effectiveness of micro-learning media in improving secondary school students' conceptual understanding of science and technological literacy (RM 3)? This study aims to contribute to this body of knowledge by developing and evaluating microlearning media for secondary school science education that explicitly integrates technological literacy components.

METHOD

This study uses a Research and Development (R&D) approach to develop, validate, and test the effectiveness of technological literacy-based micro-learning media for science learning in secondary schools. The R&D approach was chosen because the research focuses not only on testing relationships among variables but also on producing pedagogical artefacts in the form of learning media that are feasible, valid, and effective for use in real-life learning contexts (Marlina et al., 2025; Son & Ha, 2024). The development model used is a simplified adaptation of the Borg & Gall model, tailored to the research needs, with three main stages as shown in Figure 1.

Figure 1. Research Stages

The research was conducted over 8 months (March – October 2025). The needs analysis stage was conducted in March 2025, the design and development stage from April to August 2025, and the implementation and evaluation stage from September to October 2025. This method was designed to answer three main research problems. Research problem 1 (RP1) focuses on identifying the characteristics and needs of secondary school science learning to develop technological literacy-based micro-learning media. The main results of this stage are learning media design specifications, including learning objectives, microlearning content characteristics, digital media forms, and the technological literacy elements to be developed. Research problem 2 (RP2) aims to assess the level of validity and feasibility of the developed micro-learning media. The method used to address this problem formulation is expert validation, involving science, learning media, and educational technology experts. The validation process focuses on content suitability with science concepts, pedagogical quality, clarity of microlearning presentations, and integration of technological literacy into the media. Research problem 3 (RP3) aims to test the effectiveness of micro-learning media in improving students' conceptual understanding of science and technological literacy. To achieve this, a quasi-experimental pretest–posttest design was used in the experimental and comparison groups. The experimental group used the developed micro-learning media, while the comparison group used conventional learning or media commonly used in schools. A summary of the relationship between the problem formulation, the method, and the expected results is shown in Table 1.

Table 1. Description of Research Subject

No.	Research Problem	Research Stage	Time	Research Subject	Number of Participants
1.	RP1	Need analysis	March 2025	Science Teacher	3
				Student	60
2.	RP2	Development and Expert Validation	April – August 2025	Science Teacher	3
				Lecturer	3
3.	RP3	Quasy Experiment	September – October 2025	Student	204

This study involved several groups of participants tailored to the Research and Development (R&D) stages, namely needs analysis, product validation, and effectiveness testing. This study was conducted in Sintang Regency, approximately 150 km from the centre of Pontianak, the capital of West Kalimantan, Indonesia. In the needs analysis stage, participants were 60 high school students in Sintang Regency, selected through purposive sampling. The criteria for student selection were having attended lessons using microlearning media within the last 6 months. The teachers involved consisted of 6 science teachers from three public junior high schools in Sintang Regency. Teacher selection was carried out using random sampling. Students were selected from grades VIII and IX with the following criteria: (1) having attended science lessons regularly, (2) having basic access to digital devices, and (3) having never used microlearning media systematically. The science teachers involved had at least two years of teaching experience and were actively teaching science subjects. In the product validation stage, participants included 10 experts: 5 science teachers, 2 lecturers from the Mathematics and Natural Sciences Department of the Faculty of Teacher Training and Education, Tanjungpura University, Pontianak, and 3 lecturers in educational technology.

The experts were selected based on academic qualifications of at least a master's degree, professional experience in their field, and involvement in the development or research of technology-based learning media. In the effectiveness test stage, participants were 204 high school students from the same 3 senior high schools, divided into an experimental group (102 students) and a comparison group (102 students). Group selection was conducted using the intact-group technique to maintain the naturalness of the learning experience. The participant criteria at this stage included: (1) curriculum equivalence, (2) relatively similar initial ability levels based on pretest results, and (3) willingness to follow the entire learning series. Research instruments were developed to support each stage of research and development (R&D), namely needs analysis, product validation, and testing the effectiveness of microlearning media. Table 2 displays the type and purpose of each instrument.

Table 2. Instrument

No.	Instrument	Indicator	Research Stage	References
1	Needs Analysis Questionnaire	Identifying the needs, preferences, and characteristics of participants as a basis for developing learning media	Needs Analysis	Bayar & Ağgül (2023)
2	Technology Literacy Scale	Measuring participants' ability to understand, use, and utilise digital technology	Development Expert Validation	Farahiba (2022)
3	Expert Validation Sheet	Assess the content validity, suitability and appropriateness of learning media through expert assessment.	Expert Validation	Saputri et al., (2023)
4	Conceptual Understanding Test	Measuring the level of mastery of science concepts of participants after the application of learning media	Effectiveness Assessment	Sinha & Rinki (2025)
5	Observation Sheet	Observing behaviour, participation, and effectiveness of media implementation directly in the classroom or laboratory	Effectiveness Assessment	Rathi et al., (2022)

The needs analysis questionnaire includes both closed- and open-ended questions that assess demographics, prior experiences, and participants' expectations regarding the learning materials and methods. The data collected is quantitative (Likert scale) and qualitative (open-ended). Quantitative data analysis calculates frequencies, percentages, averages, and priority needs scores. Validity and reliability tests (e.g., Cronbach's Alpha) can also be used to test the instrument's validity and reliability. Qualitative data analysis, i.e., open-ended responses, is analysed by coding to group themes into participants' needs and preferences. The technology literacy scale uses a Likert scale to assess technical skills, understanding of digital applications, and participants' attitudes and confidence in utilising technology. The data types are quantitative and Likert scale. Quantitative data are analysed by calculating total and average scores for participants' technology literacy, and descriptive statistics (mean, SD) are used to determine literacy levels. Next, reliability testing (Cronbach's alpha) is conducted to ensure instrument consistency, or comparative analysis is conducted to compare different participant groups.The Expert Validation Sheet covers criteria such as readability, material relevance, suitability to learning objectives, and visual design. The data obtained were quantitative (validity scale) and qualitative (expert comments). Quantitative data were analysed by calculating the Content Validity Index (CVI) for each media aspect. Qualitative data were analysed to examine expert suggestions and criticisms for media improvement.

The Conceptual Understanding Test was designed based on expected competency indicators. This test is descriptive in nature to evaluate students' conceptual understanding, application of principles, and analytical skills. The data was quantitative (test scores). Data analysis was descriptive (mean, completion percentage, score distribution). Normality and differences were then tested before and after the intervention (pre-test and post-test) using a paired t-test or wilcoxon test, if the distribution was not normal. Observation sheets were used to directly observe participant behaviour, participation, and responses during the implementation of the learning media. This instrument recorded aspects such as participant engagement, interactions, emerging difficulties, and the actual application of concepts. The data were both qualitative and quantitative (behaviour frequency). Quantitative data were analysed by calculating the frequency and scores of participant engagement, interaction, and participation. Qualitative data in the form of field notes were analysed using thematic analysis to identify behavioural patterns, obstacles, and student responses. The effectiveness of the developed microlearning media was analysed using the normalised gain (N-gain) score to assess the

improvement in students' technological literacy following the learning intervention. The N-gain was calculated using the following Formula 1.

$$g = \frac{\text{Post-test Score} - \text{Pre-test Score}}{\text{Maximum Score} - \text{Pre-test Score}} \quad (1)$$

Where g represents the normalised gain score, the post-test score represents students' achievement after the intervention, the pre-test score represents students' initial achievement before the intervention, and the maximum score refers to the highest possible score that could be obtained. The use of N-gain allows the measurement of learning improvement relative to students' initial performance levels (Smallwood et al., 2026). The categorisation of N-gain scores followed the criteria, namely: (1) great improvement if $g > 0.70$, (2) moderate improvement if $0.30 \leq g \leq 0.70$, and (3) low improvement if $g < 0.30$ (Ghomi & Redecker, 2019). Based on these criteria, the obtained N-gain scores for all dimensions of technological literacy were categorised as moderate improvement, indicating that the developed microlearning media meaningfully enhanced students' technological literacy skills. Before testing the effectiveness of the developed microlearning media, prerequisite statistical analyses were conducted to ensure that the data met the assumptions required for parametric testing. A normality test was performed using the Shapiro–Wilk test to determine whether the pre-test and post-test data were normally distributed. In addition, a homogeneity test was conducted using Levene's Test to examine the equality of variances between groups. The results indicated that the data were normally distributed and homogeneous, allowing further parametric analysis. To measure the effectiveness of the developed microlearning media in improving students' conceptual understanding and technological literacy, a paired-samples t-test was used to compare pre-test and post-test scores.

This analysis was conducted to determine whether there was a statistically significant difference in students' scores before and after the implementation of the microlearning media. The level of significance used in this study was $p < 0.05$. In addition, the improvement in students' learning outcomes was analysed using the normalised gain (N-gain) score, which quantified the magnitude of learning improvement after the intervention. The N-gain categories followed the criteria proposed by Richard R. Hake, namely high ($g > 0.70$), moderate ($0.30 \leq g \leq 0.70$), and low ($g < 0.30$) (Son & Ha, 2024). These analyses provided both statistical significance and practical interpretation regarding the effectiveness of the developed microlearning media.

RESULTS AND DISCUSSION

Results

Characteristics of Students and Teachers in the Development of Science Microlearning (RP1)

Understanding the characteristics of students and teachers is an essential initial step in developing effective microlearning media for science education. Identifying learners' needs, learning habits, technological readiness, and the instructional challenges teachers face is important to ensure that the developed media aligns with classroom learning conditions and supports meaningful learning experiences. Therefore, a needs analysis was conducted to explore the characteristics of students and teachers as the foundation for developing science microlearning media (Figure 2).

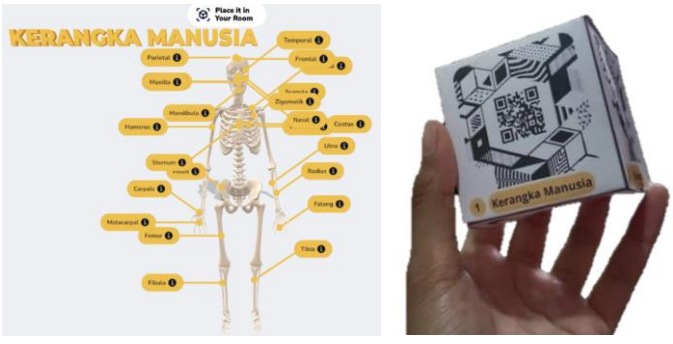

Figure 2. Science Microlearning (Human Movement System)

A needs analysis was conducted through a survey of high school students and interviews with science teachers to identify student characteristics and instructional needs. Quantitative data indicated that students were familiar with digital technology, but their technological literacy in the context of science learning was still limited. Table 3 presents the characteristics of students and teachers in the development of science microlearning.

Table 3. Characteristics of Students and Teachers

No.	Aspect	Indicator	Teacher		Student	
			Total	Percentage (%)	Concept	Difficuty Level
1	Media Ownership	Learning Media	58	96.4	Microscopic Phenomenon	High
2	Media Preference	Short Video (< 5 minutes)	49	82.1	Molecular Interaction	High
3	Media Preference	Interactive Visualitation/ Simulation	47	78.6	Mechanism	High
4	Instructional Preference	Conventional Method	12	19.3	Cellular Process	High
5	Technology Literacy	Able to critically evaluate digital science content	17	27.8	Physiological System	Medium
6	Technology Literacy	Information access	43	72.2	Interactions of Living Things	Medium

Media ownership, media preferences, instructional preferences, and technology literacy describe students' learning habits, access to digital learning resources, and readiness to use technology-based learning media. These findings were used to determine the appropriate format and features of the developed microlearning media. For example, the high percentage of students preferring short videos and interactive visualisations indicated a need for concise, visually engaging learning content.

Validity Level of Microlearning Media

The validity and feasibility of the developed microlearning media were evaluated through expert assessment and user feedback. The validation involved three expert categories: content, instructional design, and media/technology. Table 4 shows the results of expert validation of the microlearning media.

Table 4. Expert Validation Result

No.	Aspect	Mean Score	Validity Level
1	Content accuracy and relevance	4.52	Very Valid
2	Instructional design and pedagogy	4.41	Very Valid
3	Visual design and interactivity	4.47	Very Valid
4	Integration of technology literacy	4.38	Very Valid
Overall Validity		**4.45**	**Very Valid**

The research results show that microlearning media achieved a very high level of validity across all assessed dimensions. Experts emphasised the clarity of conceptual segmentation, coherence between learning objectives and activities, and the appropriate integration of digital interactions to support the development of technological literacy.

Effectiveness of Microlearning Media

The effectiveness of microlearning media was tested using a quasi-experimental pre-test and post-test design. Two outcome variables were measured: conceptual understanding of science and technological literacy. Table 5 shows student and teacher responses to each aspect.

Table 5. Feasibility Responses

No.	Aspect	Students Mean Score	Teachers Mean Score	Feasibility Level
1	Ease of Use	4.46	4.50	Very Feasible
2	Content Clarity	4.42	4.47	Very Feasible
3	Visual Attractiveness	4.51	4.55	Very Feasible
4	Learning Engagement	4.48	4.52	Very Feasible
Overall Feasibility		**4.47**	**4.51**	**Very Feasible**

Students who learned using micro-learning media showed a significant increase in conceptual understanding compared to those taught using conventional methods. Table 6 displays the average results of the technological literacy measurements.

Table 6. Pre-Test and Post-Test Results on Technological Literacy

No.	Dimention	Pre-Test Mean	Post-test Mean	N-Gain	Cronbach's Alpha
1	Accessing Digital Information	63.4	85.2	0.60	0.88
2	Interpreting Scientific Visuals	58.6	81.9	0.56	0.85
3	Evaluating Digital Science Content	54.1	78.3	0.53	0.83
Overall Technology Literacy		**58.7**	**81.8**	**0.56**	**0.85**

The results of the study showed consistent improvements across all dimensions of technological literacy, indicating that interactions with microlearning media effectively supported students' ability to interpret and critically engage with digital scientific content. The dimension "evaluating digital science content" had the lowest N-gain score (0.53) among the technological literacy dimensions, although it was still categorised as a moderate improvement. This finding may indicate that evaluative literacy skills are more cognitively complex and require higher-order thinking processes than skills related to accessing information or interpreting scientific visuals. Evaluating digital science content involves critically assessing the accuracy, credibility, relevance, and scientific validity of information obtained from digital sources (Ghomi & Redecker, 2019). Such competencies require not only technological familiarity but also critical thinking, scientific reasoning, and information evaluation skills that generally develop over a longer learning process.

Another possible explanation is that students are more accustomed to using digital technology to access information than to analyse the quality of the information they encounter critically (Guo et al., 2014). Although the developed microlearning media provided interactive, technology-based learning experiences, the learning activities may have focused more on understanding and visualising science concepts than on explicit training in evaluating digital scientific information. As a result, improvements in evaluative literacy skills were lower than in other dimensions.

Discussion

Characteristics of Students and Teachers in the Development of Science Microlearning (RP1)

Survey results showed that 96.4% of teacher respondents stated that their students owned smartphones. This high level of device ownership indicates that barriers to technology access are no longer a major issue in implementing digital learning in secondary schools. This finding aligns with various studies showing that mobile device penetration among Indonesian adolescents has reached very high levels, even surpassing personal computer ownership (Zuccarini & Malgieri, 2024). In the context of microlearning, smartphone ownership is a crucial prerequisite, as it relies heavily on fast, flexible, and mobile access. Microlearning is designed to be accessed briefly, repeatedly, and contextually, making it highly compatible with the personal, on-demand nature of smartphone use (Senadheera et al., 2024). Therefore, this finding provides empirical justification for developing science microlearning with an adequate infrastructure foundation at the student level.

However, device ownership does not automatically correlate with pedagogical readiness. Several studies confirm that the success of digital learning is determined more by the quality of instructional design and user technological literacy than simply the availability of devices (Backfisch et al., 2021; Ghomi & Redecker, 2019). Therefore, while device ownership demonstrates a highly supportive environment, other aspects, such as technological literacy and learning preferences, require more critical analysis. The preference for short videos is a characteristic of the digital

generation, accustomed to concise, concise, and to-the-point content. Shorter video duration significantly increases retention rates and learning engagement (Guo et al., 2014). In the science context, short videos allow for segmented presentations of complex concepts, thereby reducing learners' cognitive load.

Meanwhile, the high preference for interactive visuals and simulations reflects learners' need for concrete representations of abstract science concepts. Science, particularly topics such as microscopic phenomena, molecular interactions, and biological mechanisms, demands a high level of abstract thinking skills. Visualisations and simulations play a crucial role as cognitive bridges between theoretical concepts and students' conceptual understanding (Mayer & Fiorella, 2022). These findings support multimedia learning theory, which holds that integrating text, images, animations, and simulations can enhance conceptual understanding when designed according to cognitive principles (Mayer & Fiorella, 2022). In microlearning, interactive visualisations are a key element because they can convey the essence of concepts quickly and meaningfully without burdening students' working memory.

Only 19.3% of teachers stated that students still prefer conventional lectures. This figure shows the declining relevance of one-way learning methods in modern science learning. Conventional lectures tend to position students as passive recipients of information, making them less effective at building in-depth conceptual understanding, especially in processual, systemic science material. Various studies have shown that effective science learning requires active student engagement through exploration, visualisation, and reflection (Bayar & Ağgül, 2023). Microlearning, with its modular and interactive format, offers an alternative that better suits these needs. This finding reinforces the urgency of transforming science pedagogy from teacher-centred to learner-centred learning. Despite high device ownership and a preference for digital media, data show that only 27.8% of teacher respondents reported that students can critically evaluate digital science content. Conversely, 72.2% of students are still limited in their ability to access information without adequate evaluative skills.

The data in Table 2 show that concepts such as microscopic phenomena, molecular interactions, biological mechanisms, and cellular processes are categorised as high in difficulty. Meanwhile, physiological systems and dynamic system interactions are moderately difficult to model. This characteristic reflects the hierarchical and abstract nature of science. Many scientific concepts cannot be directly observed, so they require symbolic, visual, or model representations to understand. This conceptual difficulty is often a major source of misconceptions among students (Zuccarini & Malgieri, 2024). In this context, microlearning offers a relevant approach by allowing gradual, segmented presentation of concepts. Rather than presenting complex material in a single long session, microlearning breaks it into smaller units that focus on a single core concept. This approach aligns with cognitive load theory, which emphasises the importance of managing information complexity to prevent it from exceeding students' working memory capacity (Ayres & Paas, 2012).

Validity Level of Microlearning Media (RP2)

Validation results show that the content accuracy and relevance aspect obtained an average score of 4.52, which is categorised as very valid. This score indicates that the material presented in the microlearning media aligns with current, accurate scientific concepts and is relevant to the applicable curriculum. Content validity is a fundamental aspect in the development of science learning media, given that science is hierarchical and cumulative. Small errors in the presentation of concepts can impact ongoing misconceptions in students. Therefore, the involvement of content experts is crucial to ensure the suitability of concepts, the accuracy of scientific terms, and the interrelationships between subconcepts (Chi & Wylie, 2014). The very high validity score in this aspect indicates that the concept segmentation in microlearning has been appropriately carried out, breaking complex material into small units that focus on a single main idea. This approach aligns with the characteristics of microlearning, which emphasise the presentation of information in a concise, specific, and contextual manner, thereby facilitating the understanding of abstract science

concepts such as microscopic phenomena, biological mechanisms, and system interactions (Senadheera et al., 2024).

The instructional design and pedagogy aspect received an average score of 4.41, indicating very high validity. This finding indicates that the microlearning media were designed based on effective instructional design principles and aligned with modern learning theory. This finding aligns with constructivist learning theory, which emphasises that learners actively construct knowledge through interactions with materials and the learning environment. In microlearning, focused instructional design enables learners to learn independently, incrementally, and iteratively as needed. Furthermore, microlearning is considered effective at managing learners' cognitive load. Segmenting material into small units helps reduce the complexity of information that must be processed simultaneously, thus supporting deeper conceptual understanding. This aligns with cognitive load theory, which states that learning is more effective when information is presented within learners' working memory capacity (Marlina & Hamdani, 2023).

The visual design and interactivity received an average score of 4.47, indicating very high validity. This assessment indicates that the microlearning media have good visual quality and an appropriate level of interactivity to support science learning. The interactivity provided, such as self-navigation, immediate feedback, and simple activities, was also deemed effective in increasing learning engagement. The microlearning was not complex but was designed to strengthen focus on learning objectives. This aligns with the view that meaningful interactivity is more important than excessive interactivity in digital learning (Backfisch et al., 2021). The integration of the technology literacy aspect received an average score of 4.38, categorised as very valid. These results indicate that microlearning media serve not only as a means of delivering science material but also as a vehicle for developing students' technological literacy. This integration of technology literacy is crucial, as previous needs analysis results indicated that most students are still at the basic digital literacy stage, limited to accessing information without adequate evaluative skills. Well-validated microlearning media have the potential to become a tool for improving critical technological literacy, particularly in the context of science. This aligns with the digital competency framework, which emphasises that technological literacy in education must encompass the ability to understand, use, and evaluate digital information responsibly (Ghomi & Redecker, 2019).

The overall validity of 4.45, categorised as very valid, indicates that the developed microlearning media meet the eligibility standards for content, pedagogy, visuals, and technology. Consistently high validity across all aspects indicates that this media is suitable for use in the effectiveness testing and implementation stages of learning. These results confirm that the microlearning media development process has been carried out systematically and in line with users' real needs. Expert validation plays a crucial role in refining the product before it is tested with students, thereby minimising the potential for conceptual, pedagogical, and technical errors.

Effectiveness of Microlearning Media (RP3)

The feasibility responses from students and teachers (Table 4) indicate that the microlearning media is categorised as very feasible across all assessed aspects, with an overall average score of 4.47 (students) and 4.51 (teachers). This finding indicates a very high level of user acceptance of the developed media. The ease of use aspect received high scores from students (4.46) and teachers (4.50). This indicates that the microlearning media interface is intuitive and easy to navigate, thus not creating technical barriers during the learning process. Ease of use is a crucial factor in technology-based learning, as excessive technical complexity can increase extrinsic cognitive load and disrupt the learning process (Marlina et al., 2025). Easy-to-use microlearning media allows students to focus on understanding science concepts, rather than on how to operate the technology. The content clarity aspect also received very high scores from students (4.42) and teachers (4.47). Content clarity reflects the media's success in presenting science concepts in a concise, structured, and easy-to-understand manner. In the context of microlearning, content clarity is key, as the material is presented in short units that require concise, focused delivery of ideas. Previous research has shown that clarity in the presentation of microlearning material directly contributes to improved conceptual understanding, particularly in abstract science material.

The visual attractiveness aspect received the highest score compared to other aspects, from both students (4.51) and teachers (4.55). This indicates that the visual design of microlearning media is not only aesthetic but also supports learning functions. Effective visualisations, such as animations, dynamic diagrams, and simple simulations, help students construct mental representations of scientific phenomena that cannot be directly observed. This finding aligns with multimedia learning theory, which holds that integrating relevant visuals with text can improve comprehension and retention (Mayer & Fiorella, 2022). The learning engagement aspect also scored very high, with students scoring 4.48 and teachers scoring 4.52. This high level of engagement indicates that microlearning media can capture students' attention and encourage active participation in learning. Well-designed microlearning allows students to learn independently, control their pace, and repeat material as needed, ultimately increasing motivation and learning engagement (Kikas et al., 2024; Marlina et al., 2023).

The results showed that students who learned using microlearning media experienced a significant increase in conceptual understanding compared to students who learned using conventional methods. This finding can be explained by the key characteristics of microlearning, which emphasise material segmentation, a focus on a single core concept, and a gradual presentation of information. In science learning, conceptual understanding is often hindered by the complexity of the material and initial misconceptions. Microlearning media helps overcome these challenges by breaking complex concepts into smaller, easier-to-process units. This approach aligns with cognitive load theory, which states that learning is more effective when information is presented in a format that does not exceed students' working memory capacity. The results of the technological literacy measurement (Table 5) showed consistent improvement across all measured dimensions, with an overall N-gain of 0.56 (medium-high category). This improvement reflects that interaction with microlearning media not only improved understanding of science content but also significantly developed students' technological literacy.

The dimension of accessing digital information increased from a pretest score of 63.4 to a posttest score of 85.2, yielding an N-gain of 0.60. These results indicate that students became more skilled at navigating and utilising digital information sources presented in learning media. This ability is the foundation of technological literacy and a prerequisite for advanced digital skills (Marlina et al., 2023). The interpreting scientific visuals dimension also experienced a significant increase with an N-gain of 0.56. This indicates that microlearning using digital visualisation and simulation is effective in developing students' ability to understand technology-based scientific representations. The ability to interpret scientific visuals is a crucial competency in modern science learning, given that many scientific concepts and data are presented in the form of graphs, models, and digital simulations (Cheng & Xie, 2018; Marlina et al., 2024a). The evaluating digital science content dimension showed an increase with an N-gain of 0.53. Although slightly lower than the other dimensions, this increase still indicates that microlearning media can encourage students to think more critically about digital scientific information. Technological literacy encompasses not only the ability to use technology but also the ability to evaluate the credibility and relevance of information critically (Akram et al., 2021; Marlina et al., 2024b). The relatively balanced improvement across all dimensions indicates that technological literacy is developed holistically through microlearning media. This strengthens the argument that technological literacy should be integrated contextually into subject learning, rather than taught as a separate skill.

CONCLUSION

This study shows that developing microlearning media for science learning in secondary schools is a relevant, valid, and effective approach to addressing science learning challenges and strengthening students' technological literacy. The results of the needs analysis revealed that although students are familiar with digital devices, their technological literacy in the context of science learning remains limited to information access and has not developed critically. In addition, abstract and microscopic science concepts are still perceived as difficult to understand through conventional learning approaches, requiring support from more contextual and interactive digital learning media. Expert validation shows that the developed microlearning media have a very high level of validity

across all aspects, including content accuracy and relevance, instructional design, visual quality and interactivity, and integration of technological literacy. These findings indicate that the developed media have met the pedagogical and technological standards required for use in science learning in secondary schools. Effectiveness testing shows that using microlearning media significantly improves students' conceptual understanding of science and technological literacy compared to conventional learning. Consistent improvements across all dimensions of technological literacy confirm that pedagogically designed technology integration in science learning can equip students with functional and critical digital skills. Thus, microlearning media not only serve as a means of delivering material but also as a vehicle for developing 21st-century competencies. Overall, this study makes an empirical contribution to the development of technology-based learning media in science education and emphasises the importance of structured, meaningful microlearning designs. The findings of this study suggest the need for further research to expand the development and evaluation of microlearning media across broader science topics, different educational levels, and more diverse learning contexts. Future studies are also recommended to investigate the long-term impact of microlearning media on conceptual understanding, higher-order thinking skills, and technological literacy using more robust research designs such as longitudinal and experimental studies. In addition, further product development may integrate emerging technologies such as artificial intelligence, adaptive learning systems, augmented reality, and gamification to enhance the media's interactivity, personalisation, and scalability for wider educational applications.

ACKNOWLEDGEMENT

We would like to thank the Sintang Regency Education and Culture Office for granting the research permits. We also thank all junior and senior high school principals in Sintang Regency, as well as all science teachers and students who have contributed significantly to this research.

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