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DEVELOPMENT OF INTERACTIVE MATHEMATICS LEARNING MULTIMEDIA BASED ON SCRATCH USING THE 4D MODEL

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Abstract

This study is motivated by students' difficulties in understanding applied algebra, particularly when solving contextual problems, as well as the limited availability of interactive digital learning resources for applied algebra learning. Therefore, this study aims to develop and evaluate the validity, usability, and user acceptance of a Scratch-based learning medium for applied algebra using the 4D development model. The research followed the Define, Design, Develop, and Disseminate stages. The development process involved needs analysis, prototype design, and implementation through Scratch, integrating contextual tasks, visual representations, and game-based activities within a single learning environment. Validation was conducted by one mathematics education expert and two experts in educational media and ICT-based learning, while usability and user acceptance were examined through a User Acceptance Test (UAT) involving 18 prospective mathematics teachers. Data were collected using validation sheets and a UAT questionnaire and analyzed using Aiken's V coefficient and percentage-based descriptive statistics. The findings revealed a high level of validity with an average Aiken's V value of 0.85 and positive evaluations regarding usability and user acceptance, reflected in an average UAT score of 87.50%. In addition, Dr. Scratch evaluation produced a score of 20 out of 21, placing the project in the Master category. Future studies should involve junior high school students and evaluate the effectiveness of the media in classroom settings.

Keywords: applied algebra; Scratch; interactive learning media; 4D development model

Abstrak

Penelitian ini dilatarbelakangi oleh kesulitan siswa dalam memahami materi aplikasi aljabar, khususnya dalam menyelesaikan masalah kontekstual, serta terbatasnya ketersediaan sumber belajar digital interaktif pada pembelajaran aplikasi aljabar. Oleh karena itu, penelitian ini bertujuan untuk mengembangkan dan mengevaluasi validitas, usability, dan penerimaan pengguna terhadap media pembelajaran berbasis Scratch pada materi aplikasi aljabar menggunakan model pengembangan 4D. Penelitian ini dilaksanakan melalui empat tahap, yaitu Define, Design, Develop, dan Disseminate. Proses pengembangan meliputi analisis kebutuhan, perancangan prototipe, dan implementasi media menggunakan Scratch yang mengintegrasikan tugas kontekstual, representasi visual, dan aktivitas berbasis permainan dalam satu lingkungan pembelajaran. Validasi dilakukan oleh satu ahli pendidikan matematika dan dua ahli media pembelajaran serta pembelajaran berbasis TIK, sedangkan usability dan penerimaan pengguna dievaluasi melalui User Acceptance Test (UAT) yang melibatkan 18 calon guru matematika. Data dikumpulkan menggunakan lembar validasi dan angket UAT, kemudian dianalisis menggunakan koefisien Aiken's V dan statistik deskriptif berbasis persentase. Hasil penelitian menunjukkan tingkat validitas yang tinggi dengan nilai rata-rata Aiken's V sebesar 0,85 serta penilaian positif terhadap usability dan penerimaan pengguna yang ditunjukkan oleh skor rata-rata UAT sebesar 87,50%. Selain itu, evaluasi menggunakan Dr. Scratch menghasilkan skor 20 dari 21 sehingga proyek yang dikembangkan termasuk dalam kategori Master. Penelitian selanjutnya perlu melibatkan siswa SMP sebagai pengguna sasaran serta menguji efektivitas media dalam situasi pembelajaran yang sebenarnya.

***Kata kunci**: aplikasi aljabar; Scratch; media pembelajaran interaktif; model pengembangan 4D.*

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INTRODUCTION

Interactive learning media play an important role in mathematics education, particularly in supporting the understanding of abstract concepts and enhancing student engagement. Previous studies indicate that digital-based interactive media foster more dynamic and student-centered learning while improving conceptual understanding compared to conventional approaches (Fang et al., 2025; Mukambetova et al., 2025; Zhang & Nouri, 2023). Through visualization and direct interaction, such media also enhance the meaningfulness of learning and accommodate diverse student characteristics.

However, mathematics learning still faces challenges related to abstract representation, reasoning, and problem-solving, often influenced by teacher-centered practices and the use of static learning media (Bottge, 2010; My et al., 2025; Ninsiana et al., 2018). Previous studies have shown that interactive visualization technologies, such as augmented reality, can enhance students' conceptual understanding in mathematics learning (Sungkono et al., 2022). However, their implementation is often limited by accessibility and technological requirements, highlighting the need for more flexible and accessible alternatives.

Along with the advancement of educational technology, Scratch has emerged as a platform for developing interactive mathematics learning media. As a block-based visual programming environment, Scratch enables users to design animations, simulations, and game-based learning activities in an intuitive manner (Batista et al., 2016; Dúo-Terrón, 2023). Its visual and modular features support the representation of mathematical concepts and their connection to real-world contexts (Calder, 2018; Iskandar et al., 2024). From a pedagogical perspective, Scratch supports multimodal learning and computational thinking through interactive visual representations and game-based activities (Chekour et al., 2023; Fang et al., 2025; Ruamba et al., 2025).

Previous studies have shown that Scratch-based learning media can improve engagement, conceptual understanding, and problem-solving skills across various mathematics topics (Afrilianto et al., 2022; Annisa et al., 2025; Fitrianingsih et al., 2024; Gökçe & Yenmez, 2023; Hsu et al., 2022; Naim et al., 2025; Nurhayati et al., 2023; Pinto-Llorente et al., 2018; Rodríguez-Martínez et al., 2020; Sari et al., 2024; Setyaningrum et al., 2024; Syarifah et al., 2025).

Although Scratch-based mathematics learning media have been widely developed, most previous studies have primarily focused on concept visualization, animations, or quiz-based activities (Afrilianto et al., 2022; Annisa et al., 2025; Fitrianingsih et al., 2024; Gökçe & Yenmez, 2023). However, the use of Scratch to support applied algebra learning through contextual problem-solving remains limited. Applied algebra was selected because students often experience difficulties in connecting symbolic algebraic representations with contextual situations and problem-solving tasks. Therefore, learning media are needed not only to visualize algebraic concepts but also to facilitate their application in meaningful contexts.

In contrast to previous Scratch-based mathematics media, the multimedia developed in this study integrates contextual problem situations, game-based activities, drag-and-drop

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matching tasks, and immediate feedback within a single learning environment. These features encourage learners to actively engage in contextual problem-solving, identify relevant information, and revise their responses through immediate feedback.

From a pedagogical perspective, this design supports active participation and encourages learners to connect algebraic concepts with real-life situations. In addition, this research contributes to educational technology by illustrating how contextual learning, multimedia principles, gamified interaction, and computational thinking can be incorporated into a Scratch-supported algebra learning environment. Consequently, the developed media extends the use of Scratch beyond concept visualization and quiz-oriented activities toward contextual algebraic problem-solving.

Accordingly, this study focuses on the development and evaluation of a Scratch-based interactive multimedia environment for applied algebra, emphasizing its validity, usability, and user acceptance within the Four-D development framework.

METHODS

The present study adopted the Four-D model introduced by Thiagarajan et al., (1974), comprising the Define, Design, Develop, and Disseminate phasesduring. The model was selected because it provides a systematic framework for developing and evaluating educational products. The operational stages of the 4D model applied in this study are presented in Figure 1.

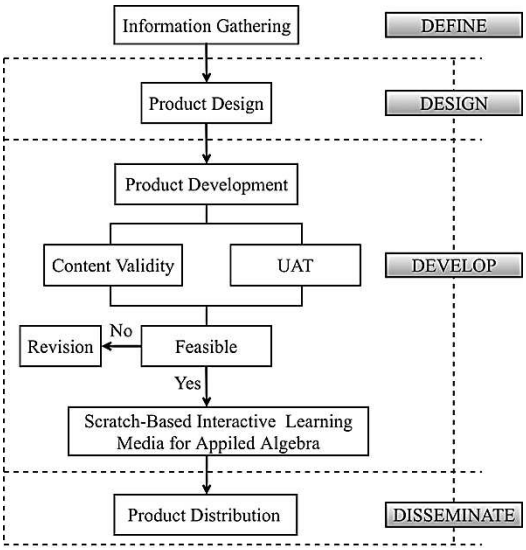

Figure 1. Operational stages of the 4D development model applied in this study

As illustrated in Figure 1, the development process began with the Define stage, which focused on identifying learning needs through information gathering. The Design stage involved preparing the initial prototype of the Scratch-based learning media. At the development phase, the multimedia product was created, reviewed by experts, and subsequently examined through a User Acceptance Test (UAT). Revisions were made based on the results of validation and testing until the product met the predetermined feasibility criteria. Finally, the Disseminate stage was conducted through product distribution.

The instruments used in this study consisted of an expert validation sheet and a User Acceptance Test (UAT) questionnaire. The expert validation sheet was developed to evaluate the suitability of the content, language, multimedia design, and usability aspects of the developed media.

The developed media was evaluated by three expert validators consisting of one mathematics education expert and two experts in

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educational media and ICT-based learning. The validators were selected purposively based on their academic qualifications and professional expertise relevant to mathematics education and educational technology. The profile and areas of expertise of the validators are presented in Table 1.

Table 1. Validators and Their Areas of Expertise

No.	Initials	Area of Expertise
1	AJ	Mathematics Education
2	ES	Educational Media and ICT-Based Learning
3	DU	Educational Media and ICT-Based Learning

The expert validation instrument consisted of 12 indicators covering material suitability, language, multi-media design, and usability aspects. The content validity of the validation instrument was analyzed using Aiken's V coefficient (Aiken, 1985), as presented in Equation (1).

$$V = \frac{\sum s}{n(c-1)} \qquad (1)$$

where V is Aiken's validity coefficient, $s = r - l_0$, r is the rating assigned by the validator, l_0 is the lowest score in the rating scale, n is the number of validators, and c is the highest score in the rating scale (Aiken, 1985).

The Aiken's V values obtained were interpreted according to the validity criteria presented in Table 2.

Table 2. Criteria for Interpreting Aiken's V Values

V	Interpretation
$0 \leq V \leq 0.40$	Low
$0.40 < V \leq 0.80$	Moderate
$0.80 < V \leq 1.00$	High

A User Acceptance Test (UAT) was conducted involving 18 prospective mathematics teachers from Universitas Pendidikan Indonesia (UPI) to obtain initial feedback regarding the functionality, presentation, and usability of the developed media.

Although junior high school students were the intended users of the media, prospective mathematics teachers were considered appropriate respondents for developmental testing because they were able to evaluate both pedagogical and usability aspects prior to classroom implementation. The UAT data were analyzed using percentage analysis as presented in Equation (2).

$$P = \frac{Obtained\ Score}{Maximum\ Score} \times 100\% \qquad (2)$$

The percentage scores obtained from the UAT were interpreted using the assessment criteria presented in Table 3.

Tabel 3. Criteria for Interpreting Percentage Scores

Percentage (%)	Categories
$P > 80$	Very Good
$60 < P \leq 80$	Good
$40 < P \leq 60$	Fair
$20 < P \leq 40$	Poor
$P \leq 20$	Very Poor

The assessment criteria shown in Table 3 were adapted from (Riduwan & Akdon, 2015). Furthermore, the developed Scratch project was evaluated using the Dr. Scratch application. The resulting scores were interpreted according to the Dr. Scratch classification, namely Basic, Developing, and Master.

RESULTS AND DISCUSSION

In accordance with the development research model employed in this study, the results are described

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through four stages following the procedures of the Four-D Model, as presented below.

Define

AThe Define stage consisted of five activities: front-end analysis, learner analysis, task analysis, concept analysis, and the formulation of instructional objectives. The front-end analysis was conducted through interviews with one mathematics teacher and three junior high school students representing high, moderate, and low-achievement groups. In addition, students' algebra assessment results were reviewed to identify learning difficulties and instructional needs.

The findings revealed several challenges in applied algebra learning. Based on the interviews, students experienced difficulties in solving contextual algebra problems and relating algebraic concepts to real-life situations. Learning activities were primarily supported by textbooks and teacher explanations, while the use of interactive digital media remained limited. These findings were supported by students' assessment results, which showed an average algebra score of 29, considerably lower than the school's minimum mastery criterion of 75. This indicates that students encountered difficulties in understanding and applying algebraic concepts within contextual problem-solving situations.

The learner analysis showed that junior high school students require visual and interactive support as they transition from concrete to abstract thinking. Furthermore, the task analysis identified key competencies related to modeling contextual situations, performing algebraic operations, and interpreting solutions. The concept analysis organized the algebra content hierarchically according to the learning objectives. Based on these findings, instructional objectives were formulated to guide the development of the Scratch-based interactive learning media.

Design

The Design stage comprised criterion-referenced test construction, media selection, format selection, and initial design. These activities resulted in a preliminary prototype of the applied algebra learning media aligned with the learning objectives and characteristics of junior high school students. The media was designed to be interactive, web-accessible, and integrated with Scratch-based game activities. A media flowchart was subsequently developed to guide the implementation process, as presented in Figure 2.

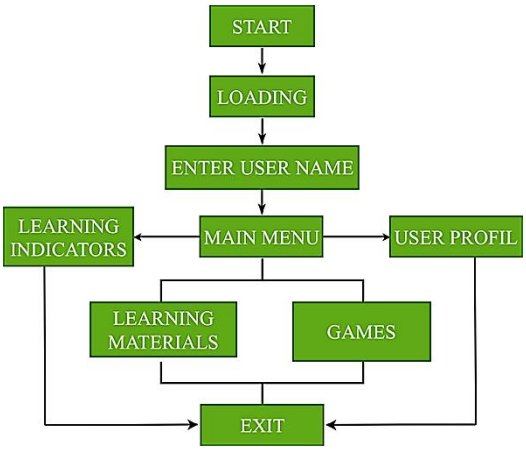

Figure 2. Flowchart of the Scratch-based interactive learning media for applied algebra.

As illustrated in Figure 2, the media consists of learning materials, learning indicators, user profiles, and game-based activities. The structure was designed to support independent learning, concept acquisition, and contextual problem-solving through

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interactive activities, immediate feedback, and repeated practice. The interface was initially designed using Canva before being implemented in Scratch.

Figure 3. Initial prototype interface of the Scratch-based interactive learning media for applied algebra

As shown in Figure 3, the initial prototype introduces fundamental algebraic concepts, including variables, constants, and coefficients, through a drag-and-drop activity. This feature was designed to encourage active learner engagement by requiring users to classify algebraic elements according to their characteristics. The immediate feedback mechanism enables users to identify and correct errors independently, while the combination of visual and interactive elements reflects multimedia learning principles that support conceptual understanding. This prototype served as the basis for further refinement during the Develop stage.

Develop

In the Develop stage, the flowchart and interface designs produced in the previous stage were implemented into an interactive learning medium using Scratch. The implementation employed block-based programming, including event-driven commands, conditional statements, loops, and variable manipulation, to manage navigation, learning activities, automated feedback, and game-based assessments.

Figure 4. Implementation of Scratch programming blocks in the Develop stage.

As shown in Figure 4, Scratch components such as sprites, backdrops, variables, and broadcast mechanisms were integrated to create an interactive learning environment. These features enabled dynamic user interaction, adaptive navigation, and immediate feedback throughout the learning process. The complete program can be accessed at https://scratch.mit.edu/projects/1331520349.

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Figure 5. (a) Initial game interface; (b) Main menu interface

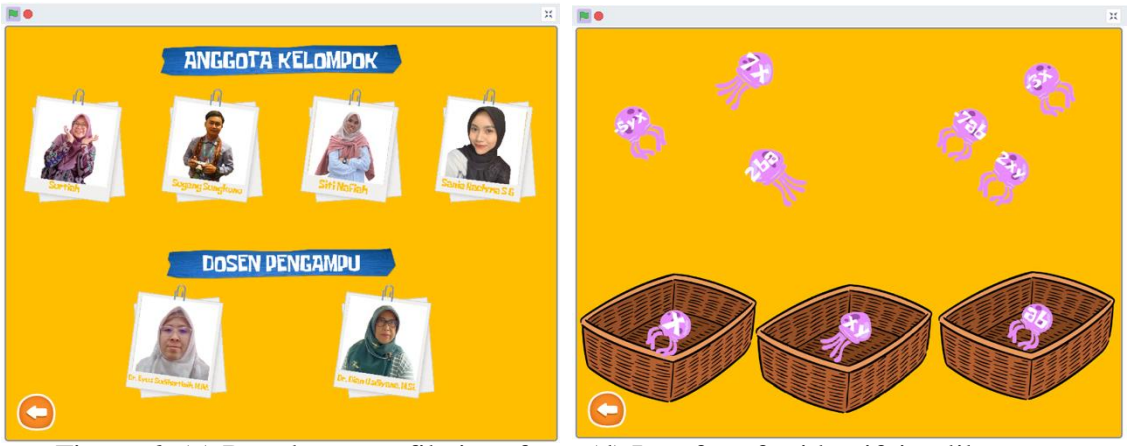

Figure 6. (c) Developer profile interface; (d) Interface for identifying like terms

Figures 5 and 6 present several interfaces of the developed media, including the initial screen, main menu, developer profile page, and an activity for identifying like terms. The media was designed to support active learning through drag-and-drop activities that require learners to classify algebraic terms according to their characteristics. This interaction is consistent with constructivist learning principles, which emphasize active participation in knowledge construction. In addition, the immediate feedback mechanism supports self-correction, while the combination of visual, textual, and interactive elements reflects multimedia learning theory by facilitating conceptual understanding through multiple representations. All visual assets used in the multimedia were either self-designed, obtained from copyright-free resources, or used in accordance with the licensing terms of the respective providers.

a After the multimedia had been developed, ratings from three experts were analyzed using Aiken's V coefficient to determine the content validity of the validation instrument. The Aiken's V values obtained for each assessment indicator are summarized in Table 4.

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Table 4. Content Validity of the Validation Instrument Based on Aiken's V.

No.	Indicator	Aiken's V	Category
1	The material is aligned with the learning outcomes.	0.89	High
2	The material is organized systematically.	0.89	High
3	The material is appropriate to students' needs.	0.89	High
4	The presented material is clear and understandable.	0.78	Moderate
5	The material is consistent with the practice exercises.	0.78	Moderate
6	The material is consistent with the visual illustrations.	0.89	High
7	The material is consistent with the game activities.	0.89	High
8	The language used is easy to understand.	1.00	High
9	The multimedia usage instructions are clear.	0.67	Moderate
10	The multimedia background design is appropriate.	0.89	High
11	The multimedia animations support the learning process.	0.78	Moderate
12	The multimedia is easy to use.	0.89	High
	Average	**0.85**	**High**

As shown in Table 4, the average Aiken's V value was 0.85, indicating a high level of content validity. Most indicators achieved high validity scores, suggesting that the experts considered the developed media appropriate in terms of content suitability, organization, visual presentation, and integration of game-based activities. In particular, the high ratings for learning outcomes alignment, material organization, and consistency between instructional content and interactive features indicate that the media was able to support the intended learning objectives.

Several aspects, including material clarity, consistency with practice exercises, multimedia animations, and usage instructions, received moderate validity scores. These findings suggest the need to improve the clarity of explanations, strengthen the connection between learning materials and exercises, and provide clearer guidance for users. Accordingly, revisions were made to the instructional guidance, visual design, and learning activities before proceeding to the user acceptance testing stage.

A User Acceptance Test (UAT) involving eighteen prospective mathematics teachers was conducted to evaluate the functionality, presentation, and usability of the developed media. Prospective teachers were selected due to their pedagogical background and ability to assess instructional and usability aspects. The data were analyzed using the percentage scoring method adapted from (Riduwan & Akdon, 2015)and interpreted based on the criteria in Table 3. The results are presented in Table 5.

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Table 5. Results of User Acceptance Test (UAT)

No	Rated Aspects	Percentage (%)	Category
1	Images and text are clearly displayed.	**80.56**	Very Good
2	The game is easy to operate.	**93.06**	Very Good
3	The material is consistent with algebra concepts.	**90.28**	Very Good
4	The exercises measure students' understanding.	**84.72**	Very Good
5	The language is clear and easy to understand.	**88.89**	Very Good
6	The game design attracts students' interest.	**87.50**	Very Good
	Average	**87.50**	Very Good

The results summarized in Table 5 indicate that all evaluated aspects were classified within the Very Good category, with scores ranging from 80.56% to 93.06%. The highest score was obtained for ease of operation (93.06%), followed by material suitability (90.28%), language clarity (88.89%), and design attractiveness (87.50%). Although the clarity of images and text received the lowest score (80.56%), it remained within the Very Good category. Overall, the average UAT score of 87.50% indicates a high level of user acceptance among prospective mathematics teachers.

However, these findings should be interpreted as evidence of usability and user acceptance rather than instructional effectiveness, since the intended users of the media are junior high school students. Together with the expert validation results, the UAT findings indicate that the media met the expected criteria in terms of content, language, multimedia design, and usability, and was considered appropriate for its intended purpose.

O From a theoretical perspective, the integration of interactive features is consistent with constructivist learning principles, while the combination of visual, textual, and interactive elements reflects multimedia learning theory.

In addition, the organization of learning materials through visual representations, interactive tasks, and immediate feedback is aligned with Cognitive Load Theory by directing attention to essential information. As a Scratch-based learning environment, the media also provides opportunities to engage in computational thinking processes, such as classification, pattern recognition, and logical reasoning.

Furthermore, the drag-and-drop activities support the understanding of symbolic representations and relationships among algebraic concepts. Based on the recommendations provided by experts and participants, revisions were made to improve the quality and usability of the media before proceeding to the Disseminate stage.

Disseminate

The dissemination stage represents the final phase of the development process and aims to share the resulting learning product. Before implementation, t the developed Scratch project was evaluated using the Dr. Scratch platform (Moreno-León et al., 2015), an assessment tool designed to examine the quality of Scratch-based projects. The evaluation yielded a score of 20 out of a maximum of 21, indicating that t the developed media exhibited a high level of technical quality according to the Dr. Scratch evaluation framework. Detailed information on the project level, identification of bad habits, certification, and performance across evaluation aspects is presented in Figure 6.

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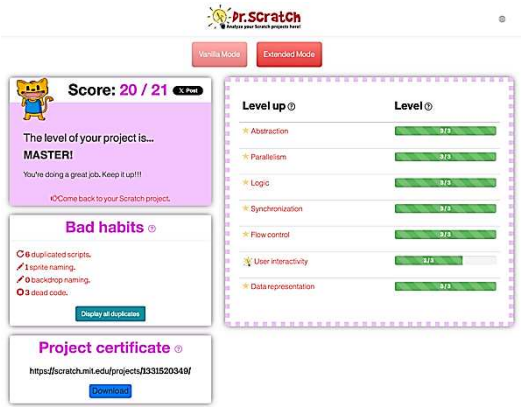

Figure 6. Dr.Scratch (A Web-Based Tool for Automatic Evaluation of Scratch Projects)

Figure 6 shows that the developed Scratch-based interactive learning media achieved the Master category based on the Dr. Scratch evaluation, with a score of 20 out of 21 and no identified bad habits in the code structure. The assessment covered several computational thinking dimensions, including flow control, data representation, abstraction, interactivity, synchronization, parallelism, and logic, reflected in the use of appropriate programming constructs. The developed media has been published and is accessible via the Scratch platform at https://scratch.mit.edu/projects/1331520349/.

The expert validation results indicated that the developed media met the expected validity criteria, while the User Acceptance Test (UAT) demonstrated a high level of user acceptance among prospective mathematics teachers. These findings suggest that the developed media meets the criteria of validity, practicality, and user acceptance.

The positive evaluations may be related to the integration of interactive features, contextual problems, and game-based activities within the developed media. From a constructivist perspective, the drag-and-drop activities and problem-solving tasks encourage active knowledge construction through interaction and exploration.

In addition, the combination of visual representations, text, animations, and immediate feedback is consistent with multimedia learning theory and may support learners in processing algebraic concepts through multiple representations.

The organization of learning materials and interactive tasks is also aligned with Cognitive Load Theory by directing attention to essential information while reducing unnecessary cognitive processing. Although learning outcomes were not measured directly, these theoretical perspectives suggest that the developed media has the potential to support conceptual understanding of applied algebra.

This finding is consistent with previous studies by Kong & Kwok (2021) and Annisa et al., (2025), which reported that Scratch-based learning environments can support engagement and conceptual exploration in mathematics learning. From a pedagogical perspective, the developed media offers an alternative approach for integrating digital technology, gamification, and contextual learning into mathematics instruction. This approach has been recognized as supporting active and exploratory learning practices (Fang et al., 2023; Soboleva et al., 2021)

However, this study is limited to expert validation and user acceptance testing involving prospective teachers and has not yet been implemented in real classroom settings. Therefore, future studies should involve junior high school students as the target users and employ more comprehensive research designs to examine the effectiveness of the developed media in actual learning contexts.

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CONCLUSIONS

This study resulted in the development of Scratch-based interactive learning media for applied algebra using the 4D development model. The findings from expert validation and the User Acceptance Test (UAT) indicate that the developed media meets the criteria of validity and practicality, with a high level of user acceptance. In addition, evaluation using the Dr. Scratch application shows that the program is classified in the Master category. Therefore, the developed media can be considered feasible and well accepted by prospective mathematics teachers.

This study was limited to expert validation and user acceptance testing involving prospective mathematics teachers. Therefore, future studies should involve junior high school students as the target users and evaluate the developed media in actual classroom settings. In addition, similar media may be developed for other mathematics topics and learning contexts.

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