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Enhancing Conceptual Understanding of Quadratic Equations through Scratch-Based Game Learning: A Constructivist Approach

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Abstract: Quadratic equations are a fundamental topic in mathematics education, but various studies show that students' conceptual understanding of this material is still low. Scratch-based learning media that have been developed previously also tend to be limited to visual aspects and have not fully integrated narratives, interactive evaluations, and learning principles that support the construction of students' knowledge. This research aims to develop a Scratch-based mathematics learning media on the square equation material for class X high school students and to test its validity, practicality, and effectiveness in facilitating students' understanding of the concepts. The novelty of this research lies in the integration of interactive visuals, narratives, and game-based evaluations designed in harmony with the principles of constructivism and the cognitive needs of students. The research used the ADDIE development model, involving 19 students from class X at one of the high schools in West Bandung Regency. Data were collected through test and non-test instruments, including questionnaires from material experts, media experts, UAT, and student responses. The results of the study show that the learning media developed meet the criteria of validity, practicality, and potential effectiveness. The improvement in learning outcomes was shown by an increase in students' average scores from 38 in the pre-test to 82.1 in the post-test, with the majority of N-Gain scores in the high category. The biggest improvement occurred in contextual problem-solving skills. In addition, this media is potentially effective in helping overcome student misconceptions, especially in distinguishing between quadratic equations and quadratic functions, and is supported by positive student responses to the engagement and ease of understanding the material.

Keywords: learning media, quadratic equations, scratch, ADDIE.

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INTRODUCTION

Mathematics education plays an important role in developing students' essential skills, such as conceptual and procedural understanding (Rittle-Johnson & Alibali, 1999). Good comprehension allows them to master other subjects (Rohenroth et al., 2024), assist students in solving problems more effectively (Siskawati et al., 2022; Wibowo et al., 2022), and assist in the development of high-level thinking skills, such as analysis, synthesis, and evaluation, that are essential for future academic and professional success (Kania et al., 2024). Therefore, mastering mathematical concepts meaningfully is the main goal of learning mathematics in schools.

One of the materials that has an important position in mathematics learning, especially at the high school level, is quadratic equations. This material is not only related to the completion of general forms ($ax^2 + bx + c = 0$), but it is also a prerequisite for the understanding of various advanced concepts, such as calculus and algebra (Kabar, 2023) Therefore, understanding the concept of quadratic equations is an important foundation for students' success in mathematics learning.

However, various studies show that students' understanding of square equation material remains relatively low. This low understanding is not only due to a lack of practice but also to specific cognitive barriers students experience. Several studies reveal that students have a weak grasp of algebraic prerequisite concepts, such as the law of zero factors (Reid O'Connor & Norton, 2024), and difficulties distinguishing between and connecting quadratic equations and quadratic functions, which lead to misconceptions (Ruli et al., 2019).

These cognitive barriers are exacerbated by students' tendency to understand quadratic equations procedurally without building a deep conceptual understanding. Learning that still emphasizes memorization of formulas and algorithmic steps causes students to remember the completion procedure without understanding the mathematical reasoning behind each step (How et al., 2022). From a cognitive perspective, this indicates that students have not developed a complete cognitive schema for quadratic equations. The complexity of the material involving algebraic symbols, graph represent ations, and solution interpretation creates a high cognitive load, making it difficult for students to process and integrate information meaningfully.

These problems indicate the need for a learning experience that helps students build an active, gradual understanding of concepts. From a constructivist perspective, students will find it easier to understand abstract concepts when they are actively involved in discovering and constructing their own knowledge through varied, contextual learning activities (Çibukçiu, 2025). In the context of digital technology-based learning media or games, this principle is realized through exploratory learning activities, such as drag-and-drop mechanisms and immediate feedback, which enable students to construct and revise their understanding independently. Meanwhile, from a cognitive perspective, effective learning requires a structured presentation of information and scaffolding support to aid information processing in students' memory. Gradually structured challenges and audio narration help strengthen students' cognitive schemas in understanding the abstract concept of quadratic equations.

In line with this principle, the use of digital technology-based learning media is a potential alternative to support students' knowledge development. Digital media has been shown to improve mathematical reasoning, conceptual understanding, and learning motivation by presenting simulations and interactive visualizations (Juhaevah, 2024). Various digital platforms, such as Kahoot with CAI (Wahyuni et al., 2021), GeoGebra (Aliu et al., 2025), STEM-based media (Rohendi et al., 2023), Powtoon (Safitri et al., 2025), and interactive e-modules (Agustito et al., 2025), have been proven effective in improving the understanding of mathematics concepts of high school students.

However, most of these media still focus on presenting materials and practice questions, and are not fully designed to address specific cognitive barriers to quadratic equation material. Visual media such as GeoGebra are indeed helpful for understanding graphs. However, they are often not equipped with conceptual scaffolding that guides students in interpreting the relationship between symbolic and visual representations. Meanwhile, quiz-based media such as Kahoot emphasize the motivational aspect through competition, but they facilitate less the exploration and reflection needed to build conceptual understanding. As a result, students' active involvement in building mathematical meaning remains suboptimal. One platform with the potential to be developed as a game-based learning medium is Scratch. Scratch is an easy-to-use, flexible visual programming language for developing interactive educational games (Hill & Monroy-Hernández, 2017). Several studies have developed Scratch-based mathematics learning media, including material on squared equations, and have shown the medium's feasibility in terms of design and visuals (Irawan, Kusumah, & Saputri, 2023). However, such development is still generally limited to visual display and evaluation through conventional multiple-choice quizzes, without integrating audio narratives, gradual challenges, and scaffolding mechanisms that explicitly support the construction of students' conceptual understanding. To address this gap, the learning media "X Quadratic Bird" was developed by explicitly integrating principles of constructivism and cognitivism into its feature design. This media uses a Scratch-based game mechanic with interactive visuals, audio narration as learning scaffolding, challenges structured in stages, and direct feedback to help students reflect and revise their understanding. The integration of these elements is designed to help students overcome cognitive barriers to understanding quadratic equations while building a more meaningful understanding through exploration and knowledge construction.

The novelty of this research lies in the development of a Scratch-based learning medium that not only emphasizes visual and interactive aspects but also systematically links game design to the principles of constructivism and to students' cognitive needs for understanding the concept of quadratic equations. Therefore, the purpose of this study is to develop a Scratch-based mathematics learning media on quadratic equations for high school grade X students and to test its validity, practicality, and effectiveness in facilitating students' understanding of mathematical concepts. Based on these objectives, the research questions in this study are formulated as follows: (1) What is the validity level of the Scratch-based mathematics learning medium "X Quadratic Bird" for quadratic equations in grade X of high school? (2) What is the practicality level of the "X Quadratic Bird" medium in terms of student and teacher responses?, and (3) Is the "X Quadratic Bird" medium effective in facilitating students' understanding of quadratic equations in grade X of high school?

METHOD

Research Design

The ADDIE model, as shown in Figure 1, comprises five stages: Analysis, Design, Development, Implementation, and Evaluation (Spatioti et al., 2022). First, in the Analysis stage, a literature review of relevant articles was conducted to identify learning needs and characteristics in quadratic equation material, ensuring that the media developed is relevant and can address learning needs. Second, the design stage included the team's creation of an interactive learning media storyboard featuring two students and one lecturer at a state university in West Java. Third, the development stage involved the media development process on the cratch application and validation by two material experts, media experts, and 16 User Acceptance Testing (UAT) people. Fourth, the implementation stage included the application of media in the learning process, including the opening, core activities, and closing, as observed by the observer. In the opening activity, the teacher reminded us of the prerequisite material for quadratic equations, especially one-variable linear equations and algebraic operations. The teacher gives a triggering question, such as *"What is the x value of the equation $x + 2 = 0$?"* and *"If the equation is changed to $x^2 + 5x + 6 = 0$, is the solution still the same?"* to encourage students to realize the difference in characteristics between linear equations and quadratic equations. The core activities are carried out by applying six *Discovery Learning strategies*. Furthermore, there are the students' worksheets (LKPD), which are designed to harmonize with the game's media flow. Students used LKPD to record the results of explorations, completion steps, and conceptual findings, since

Scratch does not automatically save activity results. In the closing activity, students and teachers reflected on the learning process and the concepts they had learned, and reiterated the conclusion about the solution of quadratic equations. Fifth, the evaluation stage is conducted through a summative evaluation, using pre- and post-tests to assess the effectiveness of the media in improving students' understanding of quadratic equations.

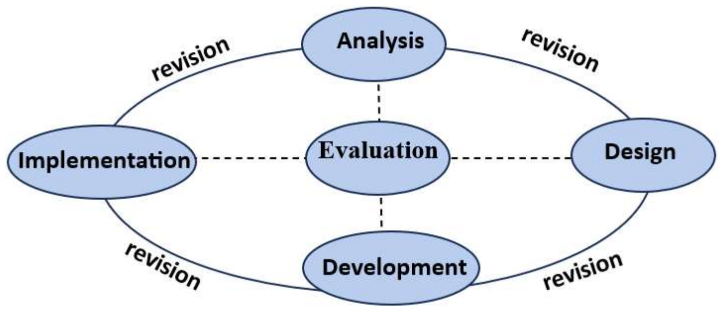

Figure 1. ADDIE Cycle

Participants

The population of this study comprised all class X students at one of the high schools in West Bandung Regency who had not studied the quadratic equation material. The sample was selected using a purposive sampling technique, yielding a class of 19 students. Where all participants are women because of the Islamic boarding school (*pesantren*), which, even though it has male and female students, separates learning activities by gender, this separation is an institutional policy that aims to maintain social decorum, foster a conducive learning environment, and align with the *pesantren*'s values and traditions.

Instrument

The research instruments consist of test and non-test instruments. The test instrument measures students' conceptual understanding of quadratic equations. The instrument was developed by researchers and validated by two subject matter experts and two media experts. The media expert is a lecturer at one of the universities in Bandung, with 8+ years of experience teaching multimedia courses in mathematics. The material expert is a teacher experienced in teaching mathematics in junior and senior high schools, and involves two colleagues as supporting validators. The test is structured based on indicators of concept comprehension (Hidayat et al., 2024) includes the ability to: (1) restate the meaning of quadratic equations and their general forms, (2) classify equations based on discriminant values, (3) provide examples and non-examples, (4) solve quadratic equations by precise methods, and, (5) solve contextual problems. During the test, students are not allowed to use books, calculators, Google, AI, or other tools.

Meanwhile, the non-test instrument in the form of a questionnaire, consisting of (1) a Material Expert Test Questionnaire, assesses the suitability of the material with competence, the accuracy of the material, the suitability of the practice questions, and the clarity of the presentation of the material (Ningsih & Adesti, 2019), (2) Media Expert Test Questionnaire, assessing aspects of the content/content of learning media, the usefulness of learning media, and the appearance of learning media,(3) User Acceptance Test (UAT) questionnaire, assessing the appearance, language, programming, material, interest, and usefulness of the media (Permata et al., 2024; Azlan et al., 2016; Razami et al., 2022),

(4) student response questionnaire, which assesses the attractiveness of media, suitability of use, material understanding, learning motivation, and group learning (Lu'luilmaknun et al., 2021) The questionnaire of material experts and media experts was filled in by a mathematics education expert. The UAT questionnaire was completed by prospective mathematics education teachers and contains both closed-ended and open-ended questions to elicit more in-depth responses. In contrast, the student response questionnaire is completed by students to gauge their perceptions of the media used. The non-test questionnaire used in this study focused on aspects of validity, feasibility, and acceptance of learning media, as well as students' perception of media use. This instrument is not intended to measure a student's advanced affective or cognitive abilities in depth. This study has not examined the affective aspects and advanced cognitive processes of students, such as cognitive load, learning engagement, and self-efficacy. Therefore, further research is recommended to adopt validated instruments to examine these aspects more comprehensively.

Furthermore, a pilot test was conducted to examine its validity, discrimination power, difficulty level, and reliability. Item validity was assessed using the Pearson correlation between each item score and the total score, with a significance criterion of Sig. < 0.05. Discrimination power was analyzed using the Corrected Item-Total Correlation (CITC). The difficulty level was calculated using the difficulty index (P), which was obtained by dividing the mean item score by the maximum score of 4. Meanwhile, the reliability of the instrument was determined based on the overall Cronbach's Alpha coefficient.

Data Analysis

Data analysis techniques were adjusted to the type of data obtained (1) Concept Comprehension Test Data Analysis, pre-test and post-test data are analyzed using the *Normalized Gain (N-Gain)* formula to determine the level of improvement in students' concept understanding. The increase category refers to the N-Gain value: low (< 0.3), medium (0.3–0.7), or high (> 0.7). Furthermore, to determine the significance of the difference between pre-test and post-test scores, an inferential statistical test was performed using *a paired t-test* when the data were normally distributed and a nonparametric Wilcoxon test when they were not. Previously, the data were tested for normality using the Shapiro-Wilk test due to the relatively small sample size (n = 19). (2) Non-Test Data Analysis, data is analyzed quantitatively using an average score on the Likert scale for each assessment indicator. In UAT, in addition to quantitative data, open-ended responses are analyzed qualitatively to identify comments, inputs, and users' experiences or impressions of the media. The data on students' responses to the learning media indicate a positive perception, but the increase in students' understanding of concepts, as measured by N-Gain, remains relatively low. These findings indicate that positive perceptions of the media are not automatically associated with greater understanding of concepts. The analysis revealed several themes, including increased interest and motivation to learn, as well as more challenging learning experiences. The theme of increasing interest in learning is reflected in the student's statement, "I became more interested in learning, not bored, and feeling challenged".

RESULT AND DISCUSSION

Analysis

In the analysis stage, a literature review was conducted to identify the needs and difficulties students face in understanding the material on the Quadratic Equation. Based on previous research, many students still have difficulty understanding the basic concepts of quadratic equations, including determining the roots of quadratic equations, understanding the relationship between the coefficients and roots, and applying these concepts to solve contextual problems. Research conducted by Giawa (2023) shows that students' understanding of concepts in quadratic equation material remains relatively low because learning tends to focus on completion procedures rather than on understanding the meaning of the concepts. In addition, Bakar & Ismail (2020) found that one-way instruction makes students passive and less motivated to learn quadratic equations. Some students also have difficulty distinguishing between quadratic equations and quadratic functions, leading to misconceptions about the structure of quadratic shapes (Ruli et al., 2019). These findings show that innovations in learning media are needed to facilitate students' conceptual understanding in more engaging, interactive ways. Therefore, in this study, a Scratch-based learning media was developed to help students understand quadratic equation material through a contextual approach and involve a more meaningful learning experience.

Bird's X Squares learning media is designed to integrate quadratic equation material through an engaging contextual approach. Its development focuses on several key indicators, namely: (1) understanding the concept of quadratic equations, (2) determining the roots of quadratic equations using three solution methods (factoring, quadratic completion, and quadratic formula), and (3) solving problems related to quadratic equations. The game's stages are designed to strengthen students' conceptual understanding. For example, game activities include matching pairs between the solution method, the discriminant value, and the root type of the quadratic equation. In addition, there are also activities to identify shapes that include and do not include quadratic equations. This game-based approach is expected to increase students' understanding of quadratic equations while fostering motivation to learn through a fun experience.

Design

At this stage, the initial design of the multimedia was carried out by determining the main concept: an adventure game-based learning media focused on Quadratic equations. The concept is manifested in the form of a game that combines visual, interaction, and challenge elements, so the media is named "X Kuadrat Bird". The purpose of this design is to combine the excitement of adventure games with math problem-solving activities so that students can understand the core concepts of quadratic equations in a more fun, contextual, and meaningful way.

This media was designed by adapting the Flying *Bird game* mechanics, which are then adjusted to the square equation material. A team of three people compiled a storyboard as a development guideline. The storyboard describes the game's flow, the appearance of each scene, user interaction, and the placement of visual and material elements. All components in the storyboard align with the learning indicators for quadratic equations.

The initial media display was designed at 1024×768 pixels with an attractive visual design. The title "Welcome to Petualangan Persamaan Kuadrat" is displayed using fonts consistent with the game's theme, along with supporting visual elements to grab the player's attention. Furthermore, introductory information from the media developer and the university's origin is displayed. The display is shown in Figure 2a.

After the introduction page, players are directed to the main menu, which consists of three sections, namely: indicators, materials, and games. The indicator section contains three learning indicators related to quadratic equations. The material section includes a brief explanation and a lighter question. The game section contains the core media, an adventure game that resembles *Flying Bird*. In this section, the bird character must navigate through pipes. Between the pipes are coins containing questions about quadratic

Visual	Sketsa	Audio
Dalam frame ini terdapat background layer dengan resolusi 1024×768 pixel, teks judul, dan tombol *start*. Dengan tombol start untuk memulai permainan, lalu akan muncul kolom untuk memasukkan nama siswa, dan logo *copyright* 2025.	Welcome to Petualangan Persamaan Kuadrat (Judul) START C 2025	Fun Music

Figure 2a. Media initial appearance storyboard

Visual	Sketsa	Audio
Dalam frame ini terdapat background layer dengan resolusi 1024×768 pixel, teks "MENU" dan 4 tombol (Indikator, Materi, Game, dan X(tombol untuk kembali ketampilan awal)).	✕ MENU Indikator Materi Game	Fun Music

Figure 2b. Main menu storyboard and game view

equations. Players must answer a minimum of five questions correctly to win the game. The storyboard of the main menu and the game view are shown in Figure 2b. The material and questions in the game are drawn from the book Ministry of Education and Culture, Research and Technology of the Republic of Indonesia (2023) by Susanto et al. (2023). They are further strengthened with additional references from trusted online sources. The visual design was created in Canva, while audio elements enhanced the gaming experience. Cheerful background music creates an interactive atmosphere, while the audio explanation in the sample question section reinforces students' understanding.

Development

At this stage, game-based learning media development is carried out using the Scratch application, following the design from the previous stage. Figure 4a is a Scratch display on quadratic equations.

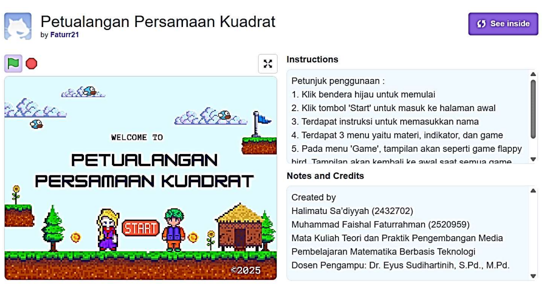

Figure 3a. Initial view of learning media

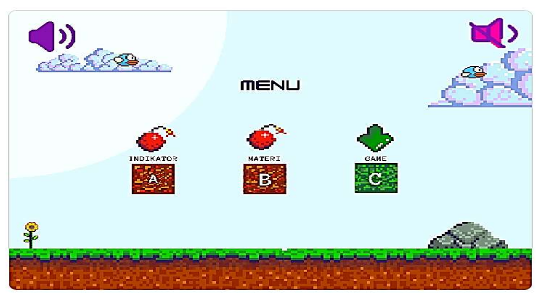

Figure 3b. Main menu view

The game can be easily accessed through https://scratch.mit.edu/projects/1245322319 and brings a friendly look for new or novice players. To begin, the user presses the green flag button, after which the layer will display the title "Welcome to Petualangan Persamaan Kuadrat" along with the start button. By clicking the start button, the game proceeds to the initial input layer, where the user is prompted to enter their name. After confirming by entering or clicking the "OK" button, the layer will move to the introduction display of the members of the media developer group. After clicking the next arrow at the bottom right, the layer will move to the main menu, as illustrated in Figure 3b.

The main menu view, as shown in Figure 3b, displays the buttons that guide the learning flow for the quadratic equation topic. This medium consists of three menus that players must navigate to complete the game: the indicator menu, the material menu, and the game menu. Each menu has a different function. The indicator menu provides information related to three quadratic equation indicators. The material menu contains in-depth questions and an in-depth explanation of the concept of quadratic equations. The game menu consists of obstacles in the form of pipes, coins containing questions, and birds as characters. If the player selects the material button, the next view will display a series of explanations and triggering questions to reinforce learning, as shown below.

Figure 4 shows the core material, which includes the triggering question "What is a quadratic equation?" to direct students' attention to the main concept. After students reflect on the question, the system displays the conclusion that the quadratic equation has the highest rank of 2. The material in this media includes definitions of quadratic equations, differences between equations and quadratic functions, and explanations of the roots of quadratic equations. In addition, a description of discriminant values and types of roots was presented, followed by three methods of solving, along with examples of problems

Figure 4. Display of the material of the spark questions and explanations

In the final section, there is an example of the application of Quadratic equations in daily life. The structure of this material is designed to provide a concise yet comprehensive understanding, from the basic concepts to their applications. Furthermore, Figure 5 shows an overview of the initial appearance and core parts of this online game.

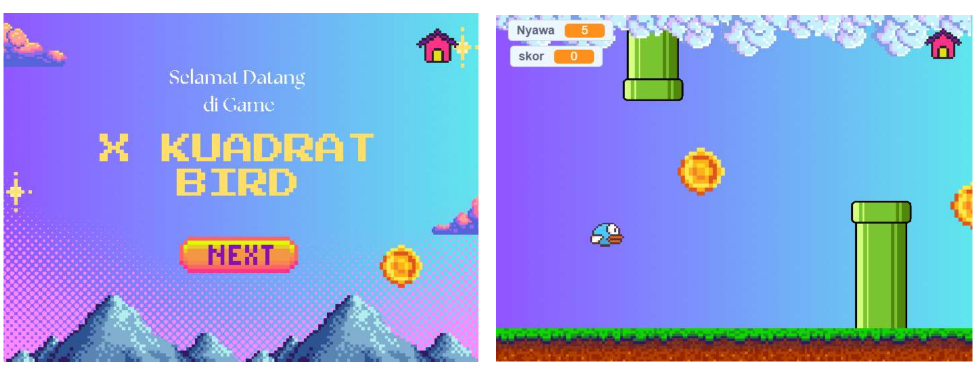

Figure 5. Initial view and core view of the game

The initial appearance of the game as shown in Figure 3a, contains the name of the game and the next button, when the player has pressed the next button it will move the layer to the game guide, then to the core of the game used in this learning medium (in the form of an online game), which is designed to resemble a flying bird game with the main character in the form of a blue bird. Players must avoid obstacles such as pipes, clouds, and ground. Each collision reduces one of five lives. Before the game starts, you will be shown instructions explaining the rules of the game. The game also includes coins that, when touched, raise a multiple-choice question with two options. A correct answer adds a score of 20 points, while an incorrect answer reduces one life. The game is declared a win if the score reaches 100, while running out of lives results in a game-over display. Figure 5 shows how the elements of play are combined with evaluation to create an interactive learning experience.

After this, the media was developed, and repeated testing was conducted with revisions before implementation tests. To ensure the accuracy and feasibility of the multimedia, the researchers conducted a validity test that included validating the materials and media. At this stage, the multimedia app is tested to collect user responses. After the development of the Scratch-based learning media is complete, functionality and effectiveness testing are conducted to ensure the media meets the learning objectives. Functional testing is performed to ensure that all application features operate as specified. This process is carried out through User Acceptance Testing (UAT), which assesses user acceptance and experience with learning media.

A total of 16 Mathematics Education students from a university in West Java participated as respondents by completing a closed- and open-ended questionnaire distributed via Google Forms. The closed-ended questions consisted of 21 items covering six assessment indicators: display (3 items), language (4 items), programming (3 items), material (4 items), interest (4 items), and usefulness (3 items). In addition, there are six open-ended questions that each represent each indicator, namely: (1) the overall appearance of the game, (2) the clarity of the use of language, (3) the ease of operation, (4) the suitability and depth of the quadratic equation material, (5) the gaming experience and interactivity, and (6) the usefulness of games in mathematics learning. The results of the user acceptance test are summarized in Figure 6 below.

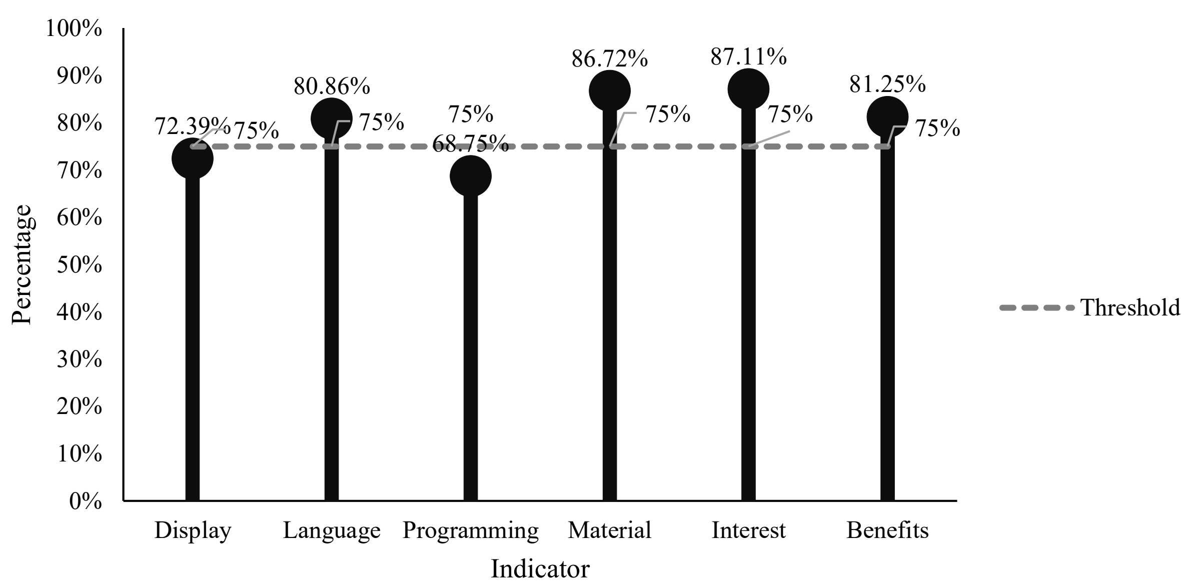

Figure 6. Results of user acceptance testing

Figure 6 shows the results of *User Acceptance Testing* (UAT) as a lollipop chart, with 75% as the minimum user acceptance rate. The results of the UAT show that almost all indicators obtained scores above the threshold, with the highest scores being in *the indicators of interest* (87.11%) and *material* (86.72%). Meanwhile, *the programming* indicator is right at the threshold. These findings show that the learning media developed are generally well received by users, both in terms of appearance, material content, and perceived benefits.

Based on Figure 6, prospective mathematics teachers showed a positive attitude towards the learning media developed. These findings are in line with previous research that stated that educational games generally receive positive responses from users. The results of the analysis of the open-ended questions also corroborate this. On the display indicator, some respondents reported that the choice of pixel-style fonts was unclear, which reduced visual comfort. They suggest using more readable fonts, even if they are not fully aligned with the design theme. Technical constraints, such as font size and button response time, can affect students' learning comfort. While they don't directly hinder understanding of concepts, these findings are important inputs for refining interface design to make it more user-friendly. On the other hand, the positive responses of students who reported feeling "happy" and "challenged" indicated that the challenges in the media were not only motor but also cognitive. Students are required to understand concepts before determining answers, so the challenges given focus on the mathematical thinking process and decision-making. This indicates that media design can encourage student cognitive engagement during the learning process.

From a language perspective, respondents found the instructions and sentences to be clear and easy to understand. In terms of programming, most of the buttons work well, but the final navigation of the material is confusing because there are no arrow keys as there were at the beginning. In addition, some respondents reported that certain buttons were *stuck*, especially in the short fill material section. Regarding the material, respondents assessed that the presentation was in order and supported understanding. The aspect of interest received a positive response; respondents felt interested, happy, and helped by the game's approach. In terms of usefulness, games are considered capable of supporting the learning process in the classroom.

In addition to being carried out by UAT, this learning media also undergoes an expert validation process to ensure the material's content is feasible and the media are of high quality before they are implemented with students. Validation was carried out by four validators, each acting as two material experts and two media experts. The assessment was carried out using a Likert-scale-based validation sheet with a comment column to provide input for improvement. The validity results were then calculated using the eligibility percentage and categorized as very valid, valid, moderately valid, or invalid based on the set score range. The media is declared suitable for use if it meets the minimum valid category requirements of both validators. The assessed aspects comprised three, namely Media Content/Content, Media Usability, and Media Display, with 16 indicators. The following is Figure 7, which contains the Results of Media Validity and Material Validity.

Figure 7 presents the results of expert validation, a combination of media and material validation, as a bar chart. The data are presented as averages of aggregate scores per aspect, not per question item, to provide a more concise, easy-to-understand picture of the quality of the learning media developed. The validation results showed that all aspects of the media and materials obtained an average score of around 3.0, indicating that the learning media are valid and

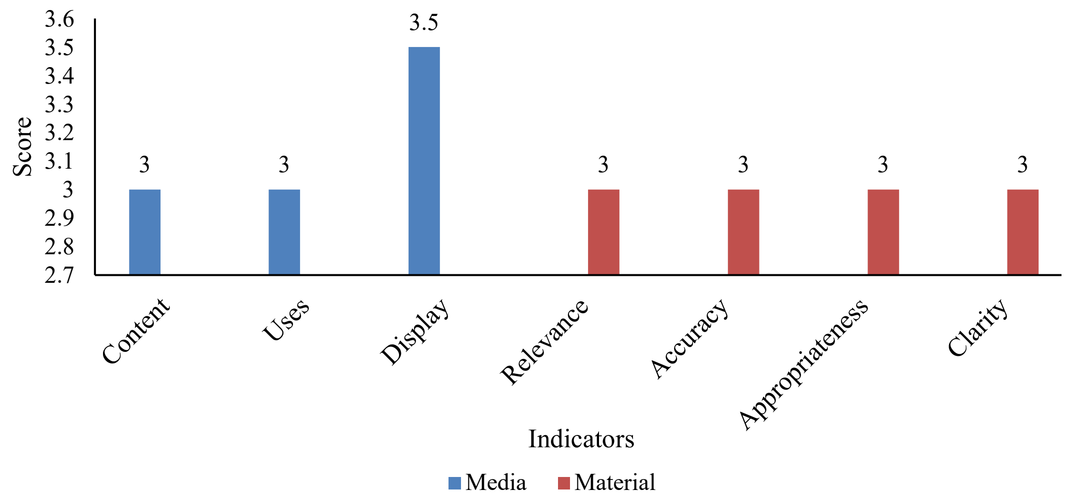

Figure 7. Media and material validity results

suitable for use. The display aspect of the media shows the highest score, above 3.5, indicating it is a superior feature of the developed learning media. However, one indicator in the display aspect, namely the color combination, scores lower than the others. This finding is a record of progress toward improving the visual appearance of the media in the next development. The results of the instrument try-out are presented in the following table 1.

Table 1. The instrument try-out

Question	r Item-Total	Validity	Differentiating Power	Category DP	Difficulty Index	DI Categories	Reliability
1	0.479	Valid	0.244	Enough	0.72	Medium	0.613 (fairly reliable)
2	0.93	Highly Valid	0.805	Excellent	0.8	Easy	
3	0.554	Valid	0.344	Good	0.95	It is Very Easy	
4	0.472	Valid	0.195	Weak	0.74	Medium	
5	0.603	Valid	0.326	Good	0.94	It is Very Easy	

Based on Table 1, all items were declared valid because their significance values (Sig.) were < 0.05. The highest discrimination power was demonstrated by Item 2, while the lowest discrimination power was found in Item 4. Based on the difficulty index, Items 3 and 5 were categorized as very easy. Overall, the instrument demonstrated moderate reliability, with a Cronbach's Alpha of 0.613.

Implementation

After carrying out the media and material validation process, the next stage is to register the media copyright with the EC002025202207 number with the Ministry of Law (Sa'diyyah et al., 2025) and implement learning media in one of the schools in West Bandung Regency, which was carried out on Friday, December 5, 2025. The implementation of learning refers to the Learning Implementation Plan prepared. The learning structure consists of three stages: introduction, core activities, and conclusion.

In the preliminary stage, the teacher starts the activity by giving greetings and making a presence, then conveys the learning objectives, the benefits of learning, and then conducts apperception by asking questions such as "how to solve linear equations $x + 2 = 0$?" to connect the student's initial knowledge with the material to be studied today. After that, it is associated with the problem of the quadratic equation "how to solve $x^2 + 5x + 6 = 0$? Is the solution the same as the linear equation?". Subsequently, the teacher will outline the activity steps using the discovery learning model and the group work rules. Furthermore, students will be divided into five groups of three or four heterogeneous members, and each group will receive an LKPD for use during learning.

After the preliminary stage is completed, the core activities follow. At this stage, learning follows six steps of discovery learning: stimulation, problem statement, data collection, data processing, verification, and generalization. In the Stimulation phase, the teacher displays the contextual problems in the Scratch media "X Kuadrat Bird". At the same time, students observe the material, identify the contextual problems, and record important points in the LKPD. Subsequently, in the Problem Statement phase, the teacher guides students to formulate problems arising from the context without providing a direct solution. Students identify important information, record what they know and what they ask, and formulate problems to be solved. During the Data Collection phase, students work in groups to gather the necessary information and begin completing the LKPD based on the discussion results. The teacher acts as a facilitator by posing provocative questions and ensuring that the entire group actively participates in discussion. Figure 6 shows an example of the LKPD content developed by one of the groups, along with documentation of student discussion activities.

Furthermore, in the Data Processing phase, students process the information obtained to develop problem-solving steps. For example, in

Figure 8. Results of LKPD and discussion activities

one of the questions, students write down the known data, determine what is asked, and then calculate the remaining class area until the form is obtained ($L = 24 - 4x^2$). In the Verification phase, students double-check the correctness of their steps and the results of their completion. At this stage, students also work on online games in the media, which include practice questions on quadratic equations to test their understanding of the concepts learned. The teacher ensures that the verification process is carried out independently by students. Then, in the Generalization phase, students are guided to conclude the concept of quadratic equations based on the results of discussion, data processing, and verification. Each group then presented its findings to the class.

After the sixth stage is implemented, the final stage, the closing, follows. The teacher invites students to reflect on what they understand and the difficulties they encounter during learning. The teacher provides reinforcement and feedback on the learning process and outcomes, then closes the activity by directing students to relearn the material through other sources to expand their knowledge.

The implementation stage shows quite complex classroom dynamics. The game-based learning media and LKPD used include several activities and questions that require students' active involvement, so in practice, the available learning time feels less than optimal for completing all stages in depth. This condition prevents some groups from fully exploring all parts of the LKPD. In addition, the limited number of facilitators, with only one teacher accompanying the learning process, results in a queue of questions from several groups at the same time. Student questions are not only about understanding mathematical concepts but also about the use of media, clarification of instructions, and correction of errors in LKPD's work. To overcome this condition, teachers apply adaptive facilitation strategies by prioritizing general questions, providing brief explanations, and encouraging students to discuss among group members. In the *Data Collection* phase, no significant conceptual difficulties were encountered. However, time constraints led some groups to complete data collection and processing activities efficiently, resulting in an analysis depth that was not fully optimal. Nevertheless, the observation results showed that students were still able to follow the learning flow and actively interact with the media and LKPD, in line with the designed learning objectives.

Evaluation

To determine the effectiveness of the learning media developed, an evaluation is conducted through pre- and post-tests administered to all students participating in the learning. The pre-test is administered before the learning process begins to measure students' initial ability with the quadratic equation material. Meanwhile, a post-test is given after learning is completed to assess students' understanding of the Scratch media "X Kuadrat Bird". The following is Figure 9, which contains the results of the students' pre-test and post-test.

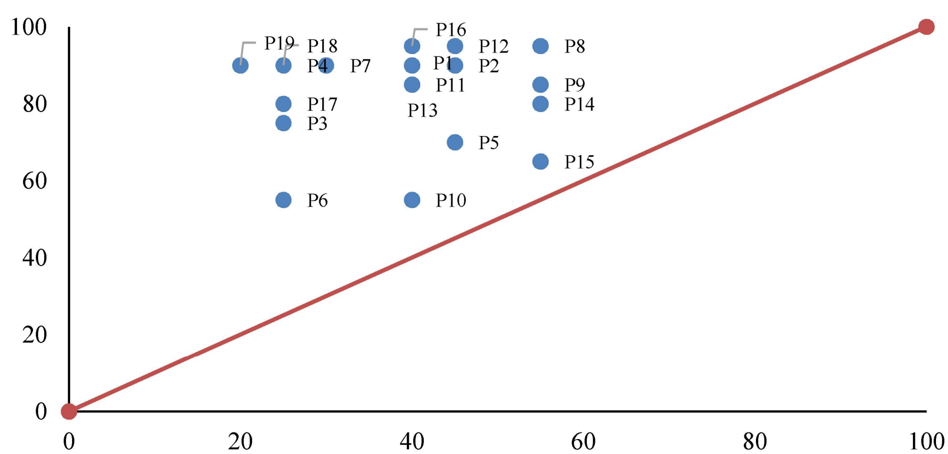

Figure 9. Pre-test and post-test results

Figure 9 presents the relationship between the pre-test and post-test scores of students, converted to a 0–100 scale. The X and Y axes are equalized to ensure proportional comparison of the values. A diagonal line $x = y$ is added as a reference line to show changes in student learning outcomes. Data points above the diagonal line show an increase in post-test values compared to pre-tests, while points below the diagonal line show a decrease, and points just above the line show a fixed value. Based on Figure 7, most data points lie above the diagonal line, indicating that most students experience improved learning outcomes after using Scratch-based learning media.

After recording the pre-test and post-test results, descriptive statistics will be presented, including the mean, standard deviation, minimum, and maximum scores. The descriptive statistics indicate that the average pre-test value is 38. Meanwhile, the average post-test score was 82.1 Meanwhile, the pre-test standard deviation of 2.38 indicates that variation in students' initial abilities is relatively small; in other words, students' initial abilities tend to be uniform in the low category. After treatment, the post-test standard deviation increased to 2.52, indicating greater variation in students' abilities, but they still tended to score high. The maximum and minimum scores increased. This increase in minimum score shows that no student is in the low category after using the developed learning media. Overall, descriptive statistics show an increase in conceptual comprehension skills across all student grade ranges, as reflected in average, minimum, and maximum scores, as well as grade distribution.

Although the standard deviation of post-test scores (SD = 2.52) is slightly higher than that of pre-test scores (SD = 2.38), this increase in variation does not necessarily indicate a widening of the gap between students with high and low initial ability. Based on the scatter plot analysis of pre-test and post-test scores (Figure 9), it can be seen that students at all levels of initial ability experience improvement in learning outcomes, without a pattern in which students with high pre-test scores achieve much greater improvement than those with low pre-test scores. Thus, the increase in standard deviation in the post-test reflects greater variation in individual student responses to Scratch-based learning media, not an indication that the media widens the gap in learning outcomes.

Furthermore, the Distribution of Student N-Gain Scores Based on Initial Ability (Pre-test) is shown in Figure 10.

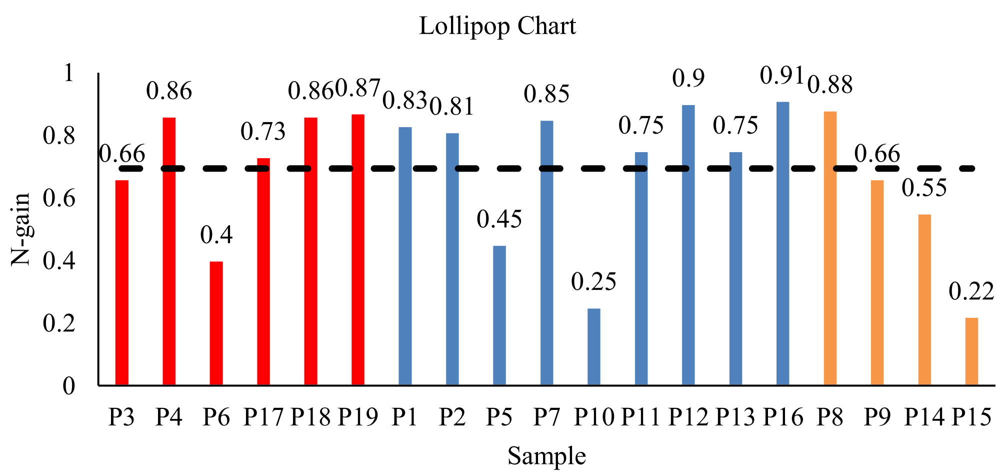

Figure 10. Distribution of student n-gain scores based on pre-test

If viewed as a whole, the majority of students show an increase in the high category. This shows that Scratch-based interactive learning media "X Kuadrat Bird" is effective in improving the understanding of the concept of quadratic equations. The biggest improvement was seen among students who scored low to moderate on the pre-test and then experienced a spike in post-test scores. This shows that the developed learning media can help students with varying levels of initial ability. Thus, based on the N-Gain analysis, the media developed are potentially effective in improving students' understanding of concepts. Previous research has also supported this study's findings, showing that Scratch can facilitate understanding of complex mathematical concepts through visual and interactive representations, such as in materials on linear functions and geometric concepts (Georgieva & Georgieva-Trifonova, 2023). In addition, Scratch is effective in improving students' computational thinking skills in mathematics (Gökçe & Yenmez, 2023).

Based on the item-level analysis presented in Table 2 below, the results indicate that the implemented intervention not only improved students' conceptual understanding of quadratic equations but also significantly enhanced their problem-solving ability, particularly in solving contextual problems. The greatest improvement was observed in the indicator of solving contextual problems (Item 5), with an 84% increase in correct responses from the pre-test to the post-test.

The analysis of the question items showed that the greatest improvement was found in the aspect of defining understanding, namely, the ability of students to identify the general form of quadratic equations and their conditions. On the other hand, the lowest increase occurred in analyzing the properties of quadratic equations, especially in determining discriminant values.

Table 2. Item-level analysis

Question Number	Indicator	% True Pre-Test	% True Post-Test	% Increase
1	Restating common sense and form	26	74	+48
2	Classifying root types based on discriminators	10	68	+58
3	Setting an example and not an example	53	95	+42
4	Solve the problem according to the method	0	42	+42
5	Solving contextual problems	0	84	+84

In addition to N-gain, a data normality test was carried out using the Shapiro-Wilk test because the sample size was less than 50 in SPSS. The test results showed that the pretest data had a significance value of 0.029, and the posttest data had a significance value of 0.005 ($p < 0.05$). Thus, the pretest and posttest data were found not to be normally distributed, so the difference analysis was conducted using the Wilcoxon test. The results of the Wilcoxon test, calculated in SPSS, showed that all students experienced an increase in learning outcomes, as evidenced by 19 positive ranks and no negative ranks or ties. The results of the Wilcoxon test showed a Z-value of "3.828 with a significance value of Sig. (2-tailed) < 0.001 ($p < 0.05$) with an effect size of 0.88, indicating that the treatment had a very large effect on student learning outcomes. Thus, there is a significant difference between pretest and posttest scores.

The qualitative data obtained from the open-ended questionnaire further strengthened the findings of this study. Thematic analysis revealed four main themes emerging from students' responses: (1) enjoyment and engagement in learning, (2) perceived ease of understanding the material, (3) preference for game-based evaluation, and (4) expectations for the use of similar media in other mathematics topics. Most students expressed positive feelings toward the Scratch-based learning media, describing the learning experience as enjoyable and engaging. One student stated, "I feel happy because I can understand the material better, and the learning method is good." Another student commented, "Learning feels fun because we can play games while studying." In addition, several students specifically highlighted the game-based evaluation component as the most enjoyable part of the learning process. A student mentioned, "The most interesting part is the evaluation section because it feels like playing a game, not taking a test." Furthermore, several students expressed their expectation that similar game-based media could be used for other mathematics topics.

These findings align with previous research indicating that the interactive and creative nature of Scratch can make learning mathematics more interesting and fun for students (Budinski et al., 2019). In contrast to findings demonstrating the effectiveness of dynamic media such as GeoGebra, some studies report that its use does not always yield consistent improvement across math learning materials or aspects (Sebsibe & Abdella, 2025). The effectiveness of GeoGebra depends on the characteristics of the material being taught and on how it is implemented in the classroom. Therefore, the findings of this study show that the "X Quadratic Bird" media has its own advantages in facilitating understanding of quadratic equations through a game-based interactive approach, which cannot necessarily be achieved as effectively by other media for the same material.

One of the problems identified in the introduction is students' misconceptions in distinguishing between quadratic equations and quadratic functions. The Scratch-based learning media developed is specifically designed to address these problems by presenting triggering questions that display the two forms side by side. Students are asked to identify which one belongs to the quadratic equation before being given a further explanation. This helps students recognize the differences between the two concepts, especially regarding the presence of the same sign and the meaning of the solution. The explanation given after students answer helps correct the misconceptions that arise. Thus, this medium not only improves understanding of concepts but also specifically helps address previously identified misconceptions.

This research suggests that Scratch-based interactive learning media, such as 'X Quadratic Bird', can help students better understand the concept of quadratic equations. From the results of development and trials, it can be seen that interactive visualizations, direct feedback, and gradual challenges make students more active and motivated in learning. Theoretically, this study confirms that interactive and gamification elements can strengthen understanding of abstract concepts, in line with the principles of constructivist and cognitivist learning. Practically, this study guides teachers and media developers. Math learning media should include clear animations or simulations, provide immediate feedback when students make mistakes or succeed, and offer a difficulty level that matches students' abilities. These principles can be applied not only to quadratic equation material but also to other mathematical topics to effectively improve the understanding of concepts.

However, this study has several limitations that should be considered when interpreting the findings. The relatively limited and homogeneous sample, along with the absence of a control group, restricts the ability to attribute improvements in students' conceptual understanding solely to the use of the media and limits the generalizability of the results. In addition, the conceptual understanding test instrument was limited to content validation through expert judgment, without pilot testing, item analysis, or statistical reliability testing, which may affect the robustness of the measurement results. Furthermore, this study did not examine affective aspects or higher-order cognitive processes, so the findings primarily reflect changes in conceptual understanding. Future studies are therefore recommended to involve more diverse samples, include comparison groups, and adopt validated instruments to measure constructs such as cognitive load, learning engagement, and self-efficacy.

CONCLUSION

Based on the research results, it can be concluded that the Scratch-based mathematics learning media for the square equation material in class X of high school has been successfully developed in accordance with the ADDIE model and meets the criteria of validity, practicality, and potential effectiveness. The increase in learning outcomes was shown by the average score rising from 38 in the pre-test to 82.1 in the post-test, as well as the dominance of the high N-Gain category, especially among students with low to moderate initial ability. Statistical analysis using the Wilcoxon test showed a significant difference between pre-test and post-test scores, with a very large effect size, confirming the strong influence of media use on learning outcomes. The analysis of the question items shows an increase in the indicator of contextual problem-solving ability. This indicates that interactive, visual, game-based media with direct feedback facilitate the gradual, meaningful construction of knowledge. In addition, the media developed is potentially effective in helping overcome student misconceptions, especially in distinguishing between quadratic equations and quadratic functions. Qualitative data from the open-ended questionnaire reinforced the quantitative findings, which showed that students felt happier, were more actively engaged, and understood the material more easily through Scratch-based learning.

Theoretically, the findings of this study support the principles of constructivist and cognitivist learning, emphasizing the importance of interaction, visualization, and gamification in understanding abstract mathematical concepts. In practice, the results of this study show that Scratch-based learning media can be a potentially effective and meaningful alternative for supporting the learning of quadratic equations in secondary schools. However, the limitations of the research in the form of limited and homogeneous samples, the absence of control groups, and instruments that have not undergone empirical tests limit the generalization of findings. Therefore, further research is recommended to use experimental designs with comparison groups, involving more diverse subjects, and to develop and test valid and reliable instruments while examining affective aspects and high-level cognitive abilities.

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

During the preparation of this manuscript, the authors used Scopus AI to identify and explore relevant academic references and Grammarly to support English grammar checking and language refinement. In addition, the built-in translation feature of Microsoft Word was used to assist in translating parts of the manuscript. The authors carefully reviewed and edited all content generated or assisted by these tools and take full responsibility for the accuracy, originality, and integrity of the published article. The use of these tools was limited to language-related support and reference exploration and did not influence the study's scientific content, data analysis, or conclusions.

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