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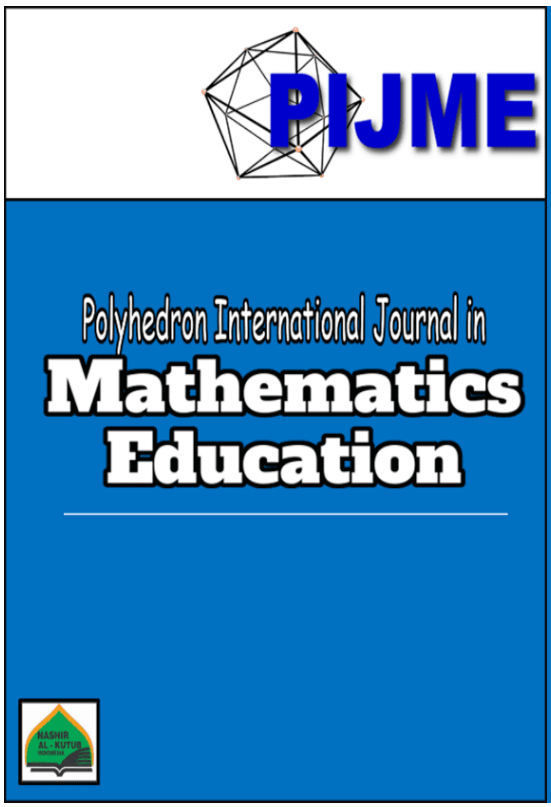

Gamifying fractions: the development of 'fraction heroes' for junior high learners

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Original Article

Gamifying fractions: the development of 'fraction heroes' for junior high learners

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Abstract
The application of digital technology in education has had a positive impact on improving learning outcomes. One form of technology integration in education is the use of educational games as interactive learning media. This study aims to develop the Fraction Heroes educational game using Unity software and to describe the quality of the developed product in terms of its validity and practicality. The method employed in this study is research and development (R&D), utilizing the ADDIE development model. The research subjects included expert validators in mathematics and educational technology, as well as seventh-grade students from two junior high schools in Banda Aceh. The research instruments consisted of expert validation sheets and student response questionnaires. The data were analyzed descriptively to assess the validity and practicality of the Fraction Heroes educational game. The results indicate that the Fraction Heroes game meets the criteria for validity and practicality as an instructional medium. The game can enhance student engagement in learning and offers an innovative alternative for teaching fraction concepts. This research suggests that integrating technology into mathematics instruction can enrich students' learning experiences in a more interactive and enjoyable manner.

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1. Introduction

The development of digital technology has brought about a transformation in the world of education (Fatihah et al., 2023; Isnawan & Alsulami, 2024; Yaniawati et al., 2023. Digital transformation allows various innovations in the learning process, including integrating technology in teaching mathematics (Muhhiban et al.,2023; Sudirman et al., 2020; 2025). Several studies have shown that technology can improve learning effectiveness, especially in helping students understand abstract concepts such as fractions (Alimuddin et al., 2023). With technology, students can access more interactive, engaging, and developmentally appropriate learning methods. One widely used approach is the development of educational games as interactive learning media that can increase student motivation and understanding (Rofiqoh et al., 2020). Educational games play an important role in education and become an innovation when technology is integrated with learning through mobile devices or smartphones (Barbieri et al., 2021).

The development of the gaming industry in Indonesia is quite rapid and has become part of the life of modern society, including students (Simatupang et al., 2011). Many students spend their free time playing games, which shows that games have great potential to be applied to learning. Educational games are games that integrate educational and learning elements so that they can increase students'

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motivation and engagement in learning (Chapman & Rich, 2018; Yu et al., 2022). In the context of math learning, educational games contain learning content in the form of math problems and materials, making them a more interesting tool than conventional methods. Educational games bring positive effects, including speed of delivery and improvement of students' skills and focus (McLean & Griffiths, 2013). Previous research shows that educational games have the potential to help students overcome these challenges more engagingly and effectively (Putrawangsa & Hasanah, 2018).

Educational games increase players' interest in learning by providing a fun experience (Zeng et al., 2020). Through this experience, the player can more easily understand and accept the material presented. According to the Cone of Experience theory proposed by Dale (1969), learning becomes more effective when a person is directly involved in an activity, such as observing a demonstration, role-playing, or participating in a real activity. In this context, educational games have the same potential because they can present interactive experiences that make players feel directly involved in learning.

Mathematics is a fundamental subject taught from primary to secondary education, but it is often challenging for students. The concept of fractions, in particular, is one of the materials considered difficult to understand because it involves complex numerical representations (Mutiarani & Sofyan, 2022). Various factors, such as low interest in learning, less varied teaching methods, and limited innovative learning media, contribute to students' low understanding of fractions (Sari & Afriansyah, 2020). Therefore, a new approach is needed to increase learning motivation and student engagement in mathematics.

Although previous studies—such as those by Permatasari et al. (2022), Faijah et al. (2022), and Enjelita et al. (2023)—have demonstrated the potential of educational games to enhance students' understanding of mathematical concepts, most have focused on general topics or employed existing platforms without specifically addressing the unique challenges of learning fractions. This study presents a novel contribution through the development of Fraction Heroes, an educational game specifically designed for Grade 7 students with a dedicated focus on fraction concepts, which are often perceived as difficult by learners. The innovation lies in the game's integration of interactive and adaptive elements that respond to students' learning pace and input, offering personalized feedback and challenges. This approach not only aims to deepen conceptual understanding but also to sustain student engagement through a more dynamic and individualized learning experience. As such, this study fills an existing gap in the literature by introducing a game-based learning tool that combines pedagogical depth with technological interactivity, specifically tailored to support the mastery of fractions.Based on preliminary observation with mathematics teachers at SMP A Banda Aceh, it was found that learning fractions still faces various obstacles. One of the main problems is students' low interest in learning fractions, especially in addition and subtraction operations of fractions with different denominators. The teacher also said that although the contextual approach has been applied, there is still a need for more innovative learning media to attract students' attention and facilitate their understanding of the concept of fractions. The lack of interactive media causes students to have difficulty connecting the concept of fractions with real applications in everyday life, so learning becomes less effective.

As a solution to the problem, this research develops the Fraction Heroes educational game designed to help students understand fractions more interactively. The game was created using Unity software and applies game-based learning principles so that students can learn in a fun and challenging way. Through this approach, students not only gain a better understanding of concepts but also improve critical thinking and problem-solving skills. With interactive elements such as point systems, challenges, and immediate feedback, students are more encouraged to engage in learning.

2. Method

2.1 Research Design

This research employs the Research and Development (R&D) method using the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (see Figure 1). The ADDIE model was selected because it has been proven effective in producing systematic and structured learning products (Branch & Varank, 2009). Moreover, the model allows for continuous revisions to ensure optimal product quality (Molenda, 2015).

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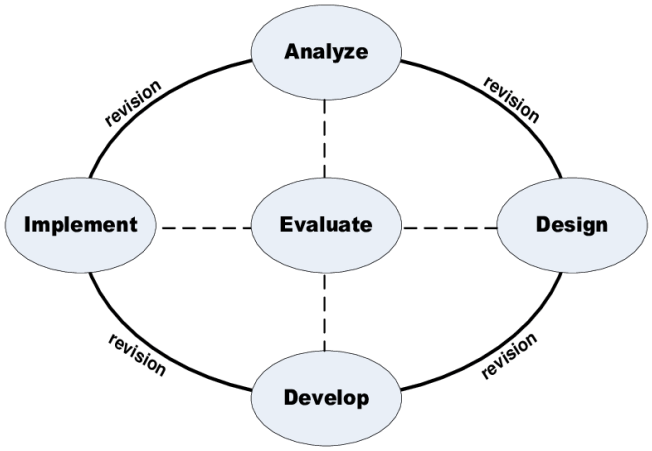
The first stage, Analysis, aims to identify the needs of students and teachers regarding game-based learning media for fraction material in seventh-grade junior high school. This stage also involves examining various challenges in learning fractions and exploring how educational games can serve as a solution to enhance students' conceptual understanding. In the Design stage, the researcher develops the game flow and interactive features of Fraction Heroes to increase student engagement. This stage also includes preparing in-game questions with varying levels of difficulty to align with students' learning progress. The Development stage involves creating the Fraction Heroes prototype using Unity software. Upon completion, the prototype is validated by subject matter experts in mathematics and educational technology to ensure its alignment with learning objectives and the quality of the content. During the Implementation stage, the game is tested with students from SMP A Banda Aceh and SMP B Banda Aceh. Throughout this trial phase, data is collected using student response questionnaires to assess the game's practicality as a learning tool. The final stage, Evaluation, focuses on analyzing the trial results to determine the extent to which Fraction Heroes meets the established practicality criteria. The findings serve as the basis for refining and enhancing the game to maximize its effectiveness in helping students understand fraction concepts.

Figure 1
Flowchart of the ADDIE



2.2 Participants

This research involves two primary groups of participants: expert validators and junior high school students. The first group consists of validators who are experts in the fields of mathematics education and educational technology. These experts are responsible for evaluating the content validity, pedagogical appropriateness, and technical quality of the Fraction Heroes educational game. Their feedback is essential to ensure that the game aligns with the intended learning objectives, presents accurate mathematical concepts, and provides an engaging and user-friendly interface. The selection of validators is based on their academic qualifications, professional experience, and relevance to the research scope, particularly those who have expertise in game-based learning or digital instructional media.

The second group of participants includes seventh-grade students from two public junior high schools in Banda Aceh: SMP Negeri 6 Banda Aceh and SMP Negeri 16 Banda Aceh. These students are involved in the implementation phase, where they interact directly with the Fraction Heroes game in a classroom setting. Their participation provides crucial data regarding the game's practicality, usability, and impact on learning motivation and conceptual understanding of fractions. Students are selected purposively to represent a range of academic abilities, ensuring a diverse perspective on the effectiveness and accessibility of the game. Prior to participation, informed consent is obtained from both the students and their guardians, and the implementation is conducted in coordination with the respective school teachers to ensure ethical and educational compliance.

2.3 Data Collection

The data in this study were collected using multiple techniques to ensure comprehensive evaluation of the Fraction Heroes educational game. First, to assess the validity of the game, validation sheets were employed and reviewed by two groups of experts: media experts and subject matter experts.

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The media experts focused on evaluating the technical aspects of the game, including visual design, navigation flow, user interface, interactivity, and overall usability. Their role was to ensure that the game meets multimedia development standards and is suitable for student use in a learning environment. Meanwhile, the subject matter experts examined the mathematical content embedded in the game, specifically the accuracy, clarity, and appropriateness of the fraction material. Their evaluation ensured that the game content aligns with curriculum standards and effectively supports the learning objectives for seventh-grade mathematics.

Next, to determine the practicality of the Fraction Heroes game from the students' perspective, data were collected through student response questionnaires administered after the implementation phase. These questionnaires were designed to capture students' experiences while using the game as a learning tool. The items included questions related to the game's ease of use, engagement level, clarity of instructions, perceived usefulness, and the degree to which the game helped them understand the concept of fractions, particularly addition and subtraction of fractions with different denominators. The students' responses provided insights into how the game functioned in real classroom settings and served as a basis for further refinement and improvement of the game.

2.4 Data Analysis

The data obtained from the validation results by the validators and the results of the student response questionnaire are then analyzed with the frequency of answers to each alternative chosen by the respondent multiplied by 100%. Assessment of the feasibility of educational games refers to several criteria by Nieveen (2007): validity and practicality. The percentage of feasibility results is converted into categories or criteria based on the assessment qualification table by Arikunto (2010), as presented in Table 1..

Table 1.
Educational Game Eligibility Criteria

Feasibility Percentage (%)	Feasibility criteria		Description
	Validity	Practicality	
$P > 80$	Very valid	Very Practical	No Revision
$60 < P \leq 80$	Valid	Practical	No Revision
$40 < P \leq 60$	Moderately Valid	Moderately Practical	Revised
$20 < P \leq 40$	Less Valid	Less Practical	Revised
$P \leq 20$	Invalid	Not Practical	Revised

Source: Arikunto (2010).

3. Results and Discussion

3.1 Results

This research produces an educational game application named Fraction Heroes with fraction material for grade VII junior high school. Fraction Heroes educational game was developed using Unity software by applying the ADDIE development model, which consists of five stages: analysis, design, development, implementation, and evaluation.

3.1.1 Analysis

At this stage, researchers conducted literature studies and field studies through observations and interviews with VII grade mathematics teachers of SMPN A Banda Aceh to identify problems and learning needs. The interview results showed that students have difficulty in fraction operations with different denominators, conversion of fractions to decimals, and applying fractions in real life. The learning media used are still conventional and less interesting, while educational games have never been implemented although teachers believe in their potential in improving student understanding. Implementing technology-based media also requires attention to the availability of devices and school policies.

Based on the analysis of the results of the literature study and field study, there is a need for the development of innovative learning media based on educational games for fraction material. Difficulty understanding fractions can lead to a weak understanding of mathematics, considering that this concept is the basis for many advanced topics. Educational games can be an effective solution because they can present material interactively, provide a more enjoyable learning experience, and encourage students to

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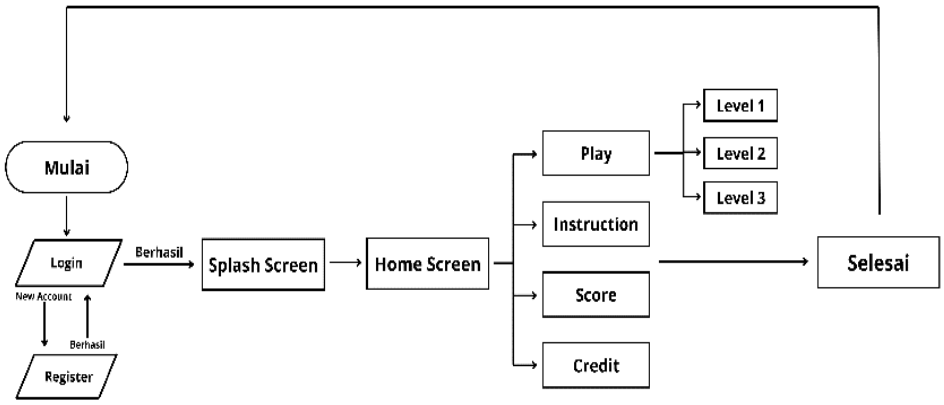
be more active in understanding the concept of fractions. By integrating challenges, immediate feedback, and concept visualization, educational games are expected to improve students' motivation, engagement, and learning outcomes in understanding fractions.

3.1.2 Design

At this stage, the game structure and interface are designed using a flowchart to ensure design suitability. A flowchart describes the flow or steps in a process or system using certain symbols. The flowchart of the Fraction Heroes educational game can be seen in Figure 2 below.

Figure 2
Flowchart of Fraction Heroes Educational Game



At the design stage, researchers also designed the name of the educational game to be developed. The name Fraction Heroes was chosen because it reflects the theme of the game and the material being taught. The word Fraction refers to the fraction material, which is the main focus in this game, while Heroes, the plural of hero, describes the player's role as a "hero" who adventures to understand and conquer the concept of fractions.

In addition, in this design stage, the game was developed by applying several key principles in developing educational games. (1) content individualization is applied by adjusting the level of difficulty and material in the game to suit the player's needs; (2) active learning is integrated by providing interactive challenges so that players can actively explore fraction concepts in various game scenarios; (3) motivation is applied through a reward system, such as giving scores or stars based on player achievements to increase player motivation; (4) scaffolding is applied by arranging game levels gradually, starting from basic concepts to more complex ones so that players can understand fraction material systematically; (5) transfer of learning where fraction concepts learned in the game can be applied in real life; and (6) assessment is applied by providing evaluation features that allow players to measure their progress in understanding fraction material (Wibawanto & Nugrahani, 2018). By applying these principles, Fraction Heroes is expected to be an effective educational game in improving students' understanding of fraction concepts through a fun and interactive learning experience.

The initial design of the Fraction Heroes educational game can be seen in Table 2.

Table 2.
Initial Design of Fraction Heroes Educational Game

Figure	Description
	Front cover of Fraction Heroes educational game
	The main menu display in the Fraction Heroes educational game consists of play, credit, hints, statistics, and a back button.

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Figure	Description
	Play menu display Hint menu display Question display Level 1 Display

3.1.3 Development

The Fraction Heroes educational game development stage is carried out using Unity software to ensure that the educational game has an attractive and interactive appearance. In addition, the development of questions that will be applied to educational games is also carried out to match the competencies that students must achieve. These questions are designed in stages, starting from the basic concepts of fractions to more complex operations, so that students can learn progressively. Each level in the educational game is designed with different difficulty levels ranging from easy, medium, and difficult according to the difficulty level of the questions. In addition, this educational game is equipped with a system of points, lives, time, and challenges to increase student motivation and involvement in solving each problem.

After being successfully developed, the educational game was validated by validators who are experts in mathematics and technology to assess feasibility and ensure compliance with learning standards. The results of this validation became the basis for making revisions before the game was tested with students. With this approach, Fraction Heroes is expected to be an effective learning media in helping students understand the concept of fractions in a more fun and interactive way.

3.1.3.1 Media Validation

The validation process was carried out by three experts, including a mathematics teacher and two lecturers from Mathematics Education Department Universitas Syiah Kuala. In this study, three aspects are measured, namely 1) quality of content and learning objectives, 2) technical quality, and 3) instructional quality. Each aspect is developed with several criteria, which are described in several indicators in the form of statements. Validation is divided into two: media validation, consisting of aspects of technical quality, and material validation, consisting of aspects of content quality and learning objectives, and instructional quality. The results of validation by validators can be seen in Table 3 below.

Table 3
Validation Results by Validators

Validator Assessment	Validator			Total Score	Criteria
	1	2	3		
Material	95%	97%	96%	96%	Very Valid
Media	94%	89%	90%	91%	Very Valid

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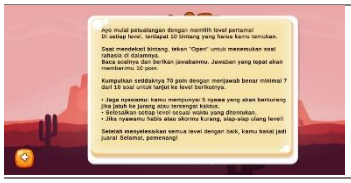
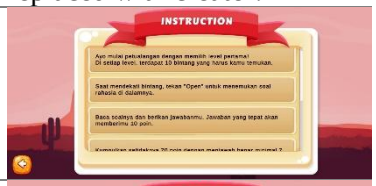
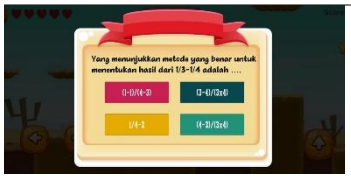
From Table 3, it can be seen that the validation results by the three material validators received an average percentage of 96% and 91% for the media with very valid criteria. The validators also provided suggestions and input on educational game media as a step of improvement and revision to improve the quality of educational games developed. The results of the revision of educational game media can be seen in Table 4.

Table 4
Revision of Fraction Heroes Educational Game

Before	Critics and Suggestions Validator	After
	The main menu arrangement is not neat, so it needs to be improved to be more organized. In addition, the existing menu names should be replaced with more representative terms to reflect each menu's function or content more accurately.	 The main menu arrangement was improved to make it more structured and neat. The hint menu is changed to instruction, the statistics menu is replaced with a score, and the credit menu is replaced with creator.
	The instruction menu is considered unattractive and boring, and the font size is considered too small.	
None	Fraction Heroes educational game development team should be added.	
	The writing of the fraction form is still wrong, which is 1/3; the Fraction should be written as $\frac{1}{3}$.	
None	Add animation to the initial display before starting the game.	

3.1.4 Implementation

The implementation stage was carried out after the educational game was declared valid by the validators. The implementation aims to assess the level of practicality of the educational game developed using two trial schemes, namely small-group and large-group trials. The small group trial involved 34 seventh-grade students from SMPN A Banda Aceh. The aim was to obtain an initial overview of the application of the educational game and identify feedback from students as users. This trial also aims to detect possible problems or obstacles that may arise during educational games so that improvements can be made before proceeding to the large group trial stage. Furthermore, the large group trial involved 64 seventh-grade students from SMPN B Banda Aceh. Data on the practicality of the educational game

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was collected through student response questionnaires, including effectiveness, efficiency, language, writing, and attractiveness. The results of these two trials were analyzed to evaluate the practicality of the educational game as a whole. Feedback obtained from students will be used as material for revising and improving educational games before they are widely implemented. The data analysis of student response questionnaire results can be seen in Table 5.

Table 5
Data Analysis of Student Response Questionnaire Results

Aspects	*NL*	$\sum xi$	$\sum xi$	Average Assessment	Percentage	Criteria
Effectiveness	3	1179	1470	4.01	80%	Very Practical
Efficient	4	1575	1960	4.02	90%	Very Practical
Language	1	419	490	4.28	86%	Very Practical,
Writing	1	413	490	4.21	84%	Very Practical
Attractiveness	5	2018	2450	4.12	82%	Very Practical
Totals	14	5488	6860	4.13	83%	Very Practical

Table 5 shows that the effectiveness aspect obtained an average score of 4.01 (80%), indicating that this game helps understand fraction material. Efficiency scored 4.02 (80%), indicating ease of use. The language and writing aspects scored 4.28 (86%) and 4.21 (84%) respectively, indicating clarity of instructions and good readability. Attractiveness scored 4.12 (82%), reflecting high student interest in the game. Overall, this game obtained an average score of 4.13 (83%), including the category "Very Practical," making it suitable for use as a fraction learning media in grade VII junior high school.

3.1.5 Evaluation

The final stage of the ADDIE development model is the evaluation stage. Evaluation is carried out based on the results of the validation and implementation stages. After the educational game was tested and received input from validators as well as responses from students in small-group and large-group trials, researchers analyzed each suggestion and criticism received. Revisions were made to improve the shortcomings found in content, design, and game features. In addition, the revision also includes adjustments to the instructions for use, visual layout, and game flow to be more effective in supporting learning. This revision stage is expected to improve the quality and practicality of educational games so that they are in accordance with the needs of students and the learning objectives to be achieved. The evaluation stage is also carried out at every other stage to ensure that the educational game development process remains fit for purpose.

3.2 Discussion

This research produces an educational game application named Fraction Heroes with fraction material for grade VII junior high school. Fraction Heroes refers to students as "heroes" in understanding fractions. In line with research conducted by Permatasari et al. (2022), Enjelita et al. (2023), Muhtarom et al. (2022), and (Arisandy et al., 2021), who developed various technology-based learning media to improve students' understanding of mathematics, this research also seeks to develop interactive educational games to help students understand fraction material. The Fraction Heroes educational game was developed using Unity software by applying the ADDIE development model, which consists of five stages: analysis, design, development, implementation, and evaluation.

This research begins with the needs analysis stage in the analysis phase. At this stage, the needs for Grade 7 mathematics learning on fraction were identified. Based on the results of interviews with a mathematics teacher at SMPN A Banda Aceh, it is known that students often have difficulty understanding fraction material, especially when applying it to the context of everyday life. In addition, the lack of technology-based interactive learning media is an obstacle in increasing student learning motivation. This opinion is in line with the research of Wangge et al. (2021), which states that monotonous learning can reduce student interest and motivation to learn. To overcome these problems, the Fraction Heroes educational game is designed as an interactive learning media that attracts students' attention and helps them understand the concept of fractions in a fun way.

In the design stage, the game structure and interface were designed, which included three difficulty levels (easy, medium, and difficult) and four main menus: play, instruction, score, and creator.

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This design is done using flowcharts to ensure its suitability. A well-designed interface can make the software easy and fun, so learning applications designed with a good interface can produce a more enjoyable learning experience for students (Kurnia & Pujiarti, 2022). At this stage, the researcher determines the name of the educational game in accordance with the theme and material being taught. The name Fraction Heroes was chosen because it reflects the main concept of the game, which is fractions. The word Fraction represents the focus of learning in this game, while Heroes describes the player's role as a hero who adventures and faces various fractions-related challenges. The name was designed to appeal to students while reflecting the educational purpose of the game.

The development stage involves the coding process using Unity software version 2020.3.43f. At this stage, each interface element that has been designed is integrated with interactive functions that support the user experience. Elements such as navigation buttons, animations, and sound effects were implemented to create an engaging and intuitive educational game. In addition, features such as the point system, level indicator, and completion time are programmed to ensure the game has a structured and challenging mechanism for the user.

During the development process, testing is carried out periodically to identify and fix any bugs or technical issues that may arise. This test includes application compatibility on various Android devices with different specifications, ensuring that the game can run optimally without experiencing a decrease in performance. Apart from the technical aspects, special attention is given to the user interface (UI) design and user experience (UX) so that the game display is visually attractive and easy to use for class VII middle school students as the target users. With this approach, the educational games developed are expected to support mathematics learning and provide a fun and educational gaming experience.

After the educational game has been developed, the next stage is to carry out validation by validators to get suggestions and input that are used to improve the educational game that has been developed. Overall, the average value of the validation results for the Fraction Heroes educational game is 96%, with very valid criteria. Thus, the Fraction Heroes educational game is suitable for mathematics learning. The validation results have not achieved a perfect score because there are still several aspects that need to be improved, especially regarding the appearance and function of the media that has been developed. The use of monotonous colors and less varied display designs makes learning media less interesting. This is in line with research by Kurnia dan Pujiarti (2022) which states that games that are designed to be interesting can increase students' enthusiasm, interest, and activeness in learning.

The implementation stage is carried out after the educational game has been revised. The educational games that have been improved are then tested on students to measure their level of practicality. Educational game trials were carried out using two schemes: small group trials at SMPN A Banda Aceh and large group trials at SMPN B Banda Aceh. During the trial, several obstacles were encountered. One of the main obstacles is that the game can only be accessed via Android-based devices, so some students who do not have an Android device cannot take part in this research. Apart from that, during small group testing, a bug was found in the form of a freeze in the game, which was thought to be caused by the specifications of the student's device, such as an insufficiently supported processor or GPU. This issue was resolved by revising the game design and code to reduce the processing load affecting low-spesification devices' performance. Several optimization steps were taken, such as lowering the graphic resolution and simplifying animations so that the game could run more smoothly. In addition, compatibility testing is carried out on various devices to ensure the game can be used on devices with minimum specifications. Guidance is also provided to students on how to use more compatible devices. With these steps, it is hoped that the problem of freezing in games can be overcome so that students can play educational games with a more optimal experience.

Another obstacle is that many students have to play repeatedly to reach the minimum score of 70 points required to advance to the next level. This phenomenon shows that educational games can increase student interest, motivation, and participation in achieving learning targets. The challenge element in this game encourages students to keep trying and trying again until they succeed, reflecting an increase in their enthusiasm for learning. This is in line with research by Nurdiana dan Asmah (2022), which also shows that one of the benefits of playing educational games in learning is increasing students' resilience in facing failure. After participating in the trial, students fill out a student response

questionnaire. Based on the questionnaire analysis of student responses, the Fraction Heroes educational game developed received an average practicality score of 83% in the very practical category.

Even though there were challenges during implementation, students and teachers responded positively to the Fraction Heroes educational game. Based on the results of the questionnaire filled out by students, the average response shows that they feel happy and motivated and find it easier to understand fractions through this game. Apart from that, this educational game is considered very interesting and effective. Thus, the Fraction Heroes educational game not only supports mathematics learning but also provides a learning experience that is fun, interactive, and relevant to current technological developments. It is hoped that this game will be the first step in presenting innovative learning media that can answer the challenges of modern education.

4. Conclusions

Based on the results of the research and development process, it can be concluded that the Fraction Heroes educational game demonstrates high levels of validity and practicality, indicating its suitability as a learning medium for fraction material at the seventh-grade level. From the validation stage, the game received an average validation score of 96%, which falls under the "very valid" category. This score was obtained through a thorough assessment conducted by both media and subject matter experts. The media experts provided evaluations related to the technical quality of the game, including aspects such as user interface design, interactivity, and overall usability. Meanwhile, the subject matter experts focused on evaluating the accuracy, relevance, and clarity of the mathematical content, particularly the presentation of fraction concepts in alignment with the curriculum. The high score reflects that Fraction Heroes meets the criteria of a well-designed and content-appropriate educational game.

In addition to its high validity, the practicality of the game was also assessed through student response questionnaires administered after gameplay sessions. The data showed that the game achieved an average practicality score of 83%, which is categorized as "very practical." This result indicates that students found the game to be engaging, easy to use, and helpful in improving their understanding of fractions, especially in operations involving different denominators. The positive student responses also highlight the game's effectiveness in increasing learning motivation and making abstract mathematical concepts more accessible and enjoyable. In light of these findings, the Fraction Heroes game is considered both pedagogically and technically appropriate for classroom use. It has the potential to serve as an innovative and effective instructional tool for helping seventh-grade students master fraction concepts through interactive and game-based learning experiences.

Limitations

This study has several limitations that should be acknowledged. First, the implementation of the *Fraction Heroes* educational game was limited to students in two junior high schools in Banda Aceh, which may affect the generalizability of the findings to other regions or educational contexts. Second, the duration of the trial was relatively short, and therefore the long-term effects of using the game on students' conceptual understanding and retention could not be fully assessed. Third, the study relied primarily on quantitative data from expert validations and student questionnaires; qualitative data such as classroom observations or interviews were not included, which may have provided deeper insights into student engagement and learning behaviors. Future research is recommended to expand the scope of implementation, include more diverse participants, and incorporate mixed-method approaches for a more comprehensive evaluation.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this research. All stages of the research, development, implementation, and analysis were conducted objectively and independently, without any financial, professional, or personal interests influencing the results.

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