Game-D: Development of an Educational Game Using a Line Follower Robot on Straight Motion Material

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***Abstract*—This research introduces Game-D, an innovative educational game designed to facilitate learning about straight-line motion through interaction with a line-following robot. Grounded in constructivist learning theory, Game-D employs gamification principles to enhance students' understanding and retention of fundamental concepts in robotics and motion physics. Using an R&D approach with the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation), Game-D underwent a series of design and testing phases to ensure alignment with educational objectives and user preferences. The sample in this study consisted of 34 students from the Science Education study program, Faculty of Teacher Training and Education, Trunojoyo University, Madura, Indonesia. Analysis results indicate that Game-D meets high standards of validity and reliability, with an average validity score of 88.25%, categorized as very valid, and a practicality score of 87.3%, categorized as very practical. Additionally, the effectiveness test yielded a high score of 86.25%, categorizing the game as very effective. These findings demonstrate that Game-D is highly valid, practical, and effective as a learning medium for straight-line motion. This study confirms that integrating a line-following robot into an educational game can improve the quality of learning, providing a viable tool to support the educational process. The media effectiveness test showed that Game-D significantly improved conceptual understanding, active student engagement and learning motivation. This underscores the role of Game-D as an effective tool in supporting straight-line motion learning, fostering a dynamic and interactive learning environment for successful education.**

***Keywords*—Game-D, educational game, line follower robot, robotics technology, straight motion material, gamification, model Analysis, Design, Development, Implementation, and Evaluation (ADDIE)**

I. Introduction

In recent years, the integration of educational games and robotics has emerged as a promising approach to improving student engagement and learning outcomes in Science, Technology, Engineering, and Mathematics (STEM) education [1, 2]. The combination of these two fields offers a unique opportunity to create interactive learning experiences to improve student engagement and understanding [3]. In this context, Game-D represents a new initiative that aims to utilize the capabilities of line-following robots to facilitate the teaching of straight motion concepts in an educational setting. Game-D capitalizes on these advances by integrating live robotics with gamified learning elements, thus enhancing student engagement, and understanding through interactive and practical application of theoretical principles. Research studies conducted [4] related to the use of line follower robots can enhance conceptual understanding of working systems.

In line with research [5], the importance of robotics in education lies in its ability to bridge theoretical knowledge with practical applications, thus fostering a deeper understanding of abstract concepts. By incorporating robotics into educational games [6], instructors can create hands-on learning experiences that promote active experimentation and problem-solving skills among students. Moreover, the gamification of educational content adds an element of fun and excitement to the learning process, motivating students to actively participate and explore complex topics [7].

Straight motion is a fundamental concept in physics and engineering, forming the basis for understanding various principles such as velocity, acceleration, and distance. Traditional methods of teaching straight motion often rely on passive instructional approaches that fail to fully engage students or demonstrate real-world applications [8]. Recognizing this challenge, Game-D seeks to address the limitations of traditional teaching methods by offering an interactive and dynamic learning environment where students can explore the principles of straight motion through hands-on experimentation and gameplay [9].

Game-D represents an innovative fusion of educational gaming and robotics technology, aiming to enhance learning about straight motion material. Developed through an iterative design process grounded in constructivist pedagogical principles, Game-D provides an interactive platform for students to engage with a line follower robot, delving into the intricacies of motion physics. In line with previous research [10], the game presents challenges and scenarios that prompt students to apply their comprehension of straight motion concepts in navigating the robot through diverse trajectories and obstacles. The research questions guiding this study are as follows:

1) How does the design of Game-D facilitate the learning process of straight-line motion, particularly through interaction with a line-following robot?
2) How does the implementation of Game-D impact the validity, practicality, and effectiveness as a straight-line motion learning media?
3) What is the influence of incorporating gamification principles in Game-D on the comprehension and retention of fundamental concepts in robotics, and what are the outcomes of student response analysis?

Through the development of Game-D, this research aims to harness the potential of educational games and robotics to revolutionize the teaching and learning of straight-line motion materials. By combining pedagogical principles with innovative technology, Game-D provides educators with a versatile tool to enhance students' understanding and retention of key concepts. As concurrent research explains in [11], the interactive nature of educational games encourages collaboration and teamwork among students, fostering a learning community that is supportive and conducive to student-to-student learning.

Uiphanit *et al.* [12] describe the process of developing an educational game, explaining the rationale, implementation strategy, and evaluation results, while exploring the theoretical framework that supports Game-D. Related research [13] on educational games explains that constructivist learning theory strongly supports the development of gamification principles. This framework formed the basis of the research approach. By disseminating Game-D, it is hoped that this research can spark future research and further innovation in the field of educational games and robotics, which in turn can promote the advancement of STEM education worldwide. This is highly relevant to the research conducted [14].

Huo [15] explains the merging of educational games and robotics technology has enormous potential to revolutionize traditional pedagogical practices and enrich students' learning experiences. Game-D serves as a quintessential example of this integration, offering a dynamic and interactive platform for teaching straight-line motion. Moving forward, sustained research and development endeavors are imperative to refine Game-D further and ascertain its efficacy across diverse educational contexts, thus advancing the fusion of educational games and robotics technology in teaching and learning.

Game-D presents numerous benefits in the field of educational gaming, particularly in teaching straight-line motion concepts through an interactive and engaging platform. Grounded in constructivist learning theory, Game-D leverages gamification principles to significantly enhance students' understanding and retention of fundamental concepts in robotics and motion physics. This interactive and dynamic approach addresses the limitations of traditional teaching methods, which often fail to fully engage students or effectively demonstrate real-world applications [16]. Overall, Game-D not only supports the educational process by fostering a deeper comprehension of straight-line motion but also cultivates a stimulating and interactive learning environment. This advancement holds promise for future research and innovation in educational gaming and robotics [17], potentially driving the advancement of STEM education globally.

II. Literature Review

The integration of educational games and robotics technology in teaching has garnered substantial attention due to its potential to enhance learning outcomes. This literature review explores various studies relevant to the development of Game-D, an educational game using a line-follower robot for teaching straight motion concepts.

A. Development of Educational Games Using Line-Follower Robots

The use of line-follower robots in educational games has been shown to be effective in teaching STEM concepts. According to Chou [18], robotics-based educational games can significantly improve student engagement and understanding of programming and engineering principles. Similarly, Evripidou *et al.* [19] demonstrated that line-following robots in game-based learning environments positively impact students' problem-solving skills and comprehension of physics concepts. These studies highlight the potential of robotics to create interactive and engaging learning experiences that promote experiential learning and exploration of complex subjects.

B. Straight-Line Motion Material

Straight-line motion is a fundamental concept in physics and engineering, forming the basis for understanding various principles such as velocity, acceleration, and distance [20]. Traditional teaching methods often rely on passive instructional approaches that fail to fully engage students or demonstrate real-world applications. Wu and Chiang [21] emphasized the importance of incorporating visual and interactive elements in teaching straight-line motion to enhance students' comprehension and retention. By providing hands-on learning experiences, educational games can simulate real-world applications of straight-line motion, offering practical understanding and promoting active experimentation.

C. Integration of Educational Games and Robotics

The synergy between educational games and robotics technology has been extensively studied, with research indicating improved learning outcomes and increased student motivation [22]. Darmawansah *et al.* [23] found that students using robot-based educational games showed greater interest and engagement in STEM subjects compared to traditional learning methods. The interactive nature of games, combined with the tangible experience of operating robots, fosters a deeper understanding of abstract concepts. This integration supports active learning, problem-solving, and inquiry-based approaches, aligning with constructivist learning principles.

D. Constructivist Learning Theory

Constructivist learning theory, as advocated by Piaget and

Vygotsky [24], emphasizes active learning where learners construct knowledge through experiences and interactions. Educational games naturally align with this theory by providing immersive and interactive learning environments. Yang and Gamble [25] highlighted the effectiveness of constructivist approaches in enhancing critical thinking and problem-solving skills. Educational games, supported by constructivist pedagogy, facilitate deeper understanding and long-term retention of learning material by engaging students in active exploration and problem-solving.

E. Gamification Principles

The application of game-design elements in non-game contexts, has been widely recognized for its ability to motivate and engage learners [26]. Alsawaier [27] discussed the potential of gamification in education, emphasizing how game elements such as points, badges, and leaderboards can drive motivation and engagement. Adams and Preez [28] further supported the positive impact of gamification on learning outcomes, suggesting that well-designed educational games can make learning more enjoyable and effective. By integrating gamification principles, educational games can enhance student motivation and participation, leading to improved learning outcomes.

F. Implications for Game-D

The development of Game-D, an educational game utilizing a line-follower robot, is grounded in these theoretical and empirical studies. By incorporating interactive game elements, hands-on robotics experiences, and constructivist learning principles [29], Game-D aims to enhance students' understanding of straight-line motion. The integration of gamification principles ensures that the game remains engaging and motivating for students, potentially leading to improved learning outcomes. Game-D seeks to address the limitations of traditional teaching methods by offering an interactive and dynamic learning environment where students can explore the principles of straight-line motion through hands-on experimentation and gameplay.

This literature review highlights the significance of integrating educational games and robotics technology in teaching STEM concepts. Previous studies underscore the effectiveness of using line-follower robots in educational games, particularly for teaching physics concepts like straight-line motion. Constructivist learning theory and gamification principles provide a robust framework for developing such educational tools. Game-D aims to leverage these insights to create an innovative and effective learning experience, contributing to the advancement of STEM education. Future research should continue to explore and refine these approaches to maximize their educational impact.

III. Method

This research utilizes an R&D approach by using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model as a methodological framework [30]. The selection of the ADDIE model is based on its ability to ensure systematic development of Game-D, offer flexible and effective development in analyzing user needs and provide continuous evaluation to ensure the final product meets the expectations of its users [31].

Fig. 1. Game-D development procedure.

Based on Fig. 1, the procedure for developing the Game-D using the ADDIE model is as follows:

Analysis phase, in this phase a comprehensive analysis is carried out to determine learning objectives and analyze sample characteristics through field surveys.

Design phase, the focus is on determining learning objectives, aligning learning objectives with curriculum objectives, designing the learning media mechanism to be used, and developing an educational game prototype that will visualize the structure and development of Game-D.

Development phase, this phase involves designing the programming language and software required to develop the Game-D robot, creating the trajectory line, installing the program, and designing the educational game interface. An important aspect of this phase is the integration of the hardware and software components of the line follower robot with the game interface.

Implementation stage, in this phase the Game-D is introduced and used in educational settings such as practicum classrooms. This phase includes a comprehensive training session for educators, which includes instructional sessions, hands-on workshops, and ongoing technical support. The instructional sessions, which were conducted over 2 weeks, demonstrated the functionality of the Game-D and their alignment with curriculum objectives. The hands-on workshop, which also lasted 2 weeks, provided educators with practical experience on the game mechanics and operation of the robot. Ongoing technical support addressed any issues during implementation. The students engaged in guided gaming sessions to explore the concept of straight-line motion through structured tasks and challenges over multiple sessions spanning 8 weeks to ensure adequate exposure and reinforcement of concepts. User feedback and performance data were collected through observations, surveys, and assessments to make necessary adjustments to the game and its integration process.

Evaluation phase, in this phase formative and summative assessments are conducted to measure the validity, practicality and effectiveness of Game-D in achieving learning objectives.

Iterative refinements were made to the game based on the evaluation findings to improve its educational value and usability. By following the ADDIE model, the Game-D development process ensured a systematic and informed approach, resulting in an educational game that effectively supports the learning of straight-line motion material using a line-following robot.

A. Research Sample

The sample in this study consisted of 34 students from the Science Education study program, Faculty of Teacher Training and Education, Trunojoyo University, Madura, Indonesia. The sample was selected to represent the wider population, ensuring that the characteristics of the sample reflect the characteristics of the entire population. The sampling technique is a simple random sample without considering the strata that exist in the population, thus ensuring unbiased representation [32].

B. Research Instruments and Analysis

The research instrument developed aims to measure the validity of media in the context of developing educational games that integrate robotics technology in education where the media validity instrument is modified from Eliza *et al.* [33], Tables 1 and 2 present the media validity instrument.

Table 1. Media validity instrument

Aspect	No	Description
Aspects of Software Engineering Components	1	Evaluate the game software's functionality in achieving learning objectives for straight motion.
	2	Assess the usability of the game interface for navigation, controls, and user experience.
	3	Rate the responsiveness and stability of the game software during play.
	4	Evaluate the compatibility of the game software across platforms (e.g., PC, mobile devices).
	5	Assess the scalability and maintainability of the software for future updates.
Visual Communication Component	1	Evaluate the effectiveness of visual elements in conveying educational concepts for straight motion.
	2	Assess the consistency of visual communication across the game interface.
	3	Rate the clarity and readability of textual information within the game.
	4	Evaluate the use of visual cues and feedback to guide player interactions and learning.
	5	Assess the overall visual appeal of the game interface.
Graphics Component	1	Evaluate the quality and realism of graphics depicting the line follower robot and its environment.
	2	Assess the appropriateness of graphics for enhancing understanding of straight motion concepts.
	3	Rate the performance of graphics rendering for smooth gameplay.
	4	Evaluate the optimization of graphics for various display resolutions and hardware.
	5	Assess the immersion and engagement facilitated by the game's graphical elements.
Material Validity Component	1	Does the material adequately cover concepts related to straight motion?
	2	How effectively does the material incorporate real-world applications of line follower robots in education?
	3	Rate the clarity and coherence of the material in presenting straight motion concepts.
	4	Evaluate the material's relevance to the educational game's learning objectives.
	5	Assess the material's alignment with the targeted age group or educational level.
	6	Evaluate the material's adaptability to different learning environments and teaching methodologies.
Linguistic Components	1	Rate the readability and comprehension of the language in the material.
	2	Evaluate how effectively the language facilitates understanding and engagement with the educational game.
	3	Assess the presence of grammatical errors or linguistic ambiguities that may hinder comprehension.
	4	Rate the appropriateness of vocabulary and terminology used to explain straight motion concepts.
	5	Evaluate the coherence and flow of language in the material.
Display Aspect	1	Assess the clarity and effectiveness of visual representations in the material.
	2	Evaluate the layout and design for readability and visual appeal.
	3	Rate the use of multimedia elements in enhancing understanding and engagement.
	4	Assess the material's accessibility for learners with visual impairments or disabilities.
	5	Evaluate the overall aesthetic appeal and professionalism of the material's presentation.

Media validity test results, focuses on three main aspects, namely the technical software component, visual communication component, and graphic component. By using this instrument, this research intends to evaluate the technical validity of the software contained in the game, as well as the effectiveness of visual communication and the quality of graphics presented to users.

Material validity test results, also looked at similar aspects, focusing on the software engineering component, visual communication component, and graphics component of the materials used in the game. Using these instruments, it is hoped to provide a deeper understanding of the technical validity and effectiveness of the visual communication and graphics of this educational game, which will form the basis for further development in the future.

Table 2. Practicality instrument

Aspect	No	Description
Ease of Use	1	How intuitive is the game interface for first-time users?
	2	Are the instructions clear and easy to follow?
	3	Is the game accessible to users with varying levels of technological proficiency?
Media Benefits	1	Does the game enhance your understanding of straight motion concepts?
	2	How effective is the game in reinforcing theoretical knowledge?
	3	Does the game facilitate active learning and engagement?
Game Elements	1	How would you rate the quality of the game graphics?
	2	Does the game provide sufficient interactivity to keep you engaged?
	3	How effective are the challenges and rewards in maintaining your interest and motivation?

The media practicality instrument was adapted from Uiphanit *et al.* [12] and developed to evaluate three main aspects: ease of use, media benefits, and game elements. The instrument was designed to assess the practicality of the educational game, Game-D, through a structured questionnaire administered to lecturers and students. The questionnaire was designed to obtain detailed feedback regarding the user experience, Table 3 presents the aspects of the Game-D practicality instrument:

Furthermore, for testing modified from Hakiki [34], Next for testing, the student response effectiveness test analysis instrument involves three main aspects: conceptual understanding, active engagement, and learning motivation. Using a rating scale that includes questions on material comprehension, student participation, and motivation, this instrument provides a comprehensive picture of student response to the Game-D. Thus, researchers can evaluate the effectiveness of Game-D in learning straight motion materials with line-following robots and understand its impact on students' learning experience. Table 4 presents the media effectiveness instrument.

Table 3. Student response effectiveness analysis instrument

Aspect	No	Description
Conceptual understanding of the material	1	How good is your understanding of the concept of straight motion after using Game-D?
	2	How confident are you in explaining the concept of straight motion after using Game-D?
	3	How often do you apply the concept of straight motion from Game-D in your daily life?
	4	Does Game-D help you understand the concept of straight motion thoroughly?
Active involvement in learning	1	How actively do you participate in learning activities with Game-D?
	2	How often do you collaborate with classmates when using Game-D?
	3	Has your interest in learning increased after using Game-D?
	4	To what extent do you feel involved in the learning process with Game-D?
Increased learning motivation	1	How motivated are you to learn with Game-D?
	2	Do you feel enthusiastic about exploring new concepts with Game-D?
	3	How much has your interest in straight-line motion material changed with Game-D?
	4	Does Game-D help improve your overall motivation to learn?

Validity data was analyzed using Aiken's V validity coefficient, a formula designed by Aiken to calculate content validity coefficients. This coefficient allows assessment of the level of validity of the data, with levels between 0.6 and 1.0 (>0.6) considered valid, while levels below 0.6 (<0.6) are considered invalid. Details of the formula and media validity criteria are presented in Table 4.

Table 4. Game-D validity assessment criteria

Average	Assessment criteria
>0.6	Valid
<0.6	Invalid

$$V = \sum S/[n(c-1)]$$

Practicality analysis was conducted using a questionnaire given to respondents to measure the effectiveness of Game-D media. In this process, the formula and criteria for practicality are measured using a Likert scale, which is then presented in detail in Table 5.

Table 5. Practicality assessment criteria of Game-D

Achievement Score	Criteria
(81–100 %)	Very practical
(61–80 %)	Practical
(41–60 %)	Somewhat practical
(21–40 %)	Slightly practical
(0–20 %)	Not practical

$$Practicality = \frac{\sum Score\ obtained}{\sum Maximum\ Score} \times 100\% \quad (1)$$

The effectiveness of Game-D uses an instrument in the form of a checklist that uses a Likert scale to collect data. The collected data will be thoroughly analyzed using descriptive statistical methods. analysis formula and effectiveness criteria are presented in Table 6.

Table 6. Criteria for assessing the effectiveness of Game-D

Achievement Score	Criteria
(85–100%)	Very effective
(75– 84%)	Effective
(60–74%)	Somewhat effective
(55–59%)	Slightly effective
(0–54%)	Not effective

$$NA = \frac{S}{M} \times 100\% \quad (2)$$

IV. Result and Discussion

The development of Game-D in the form of an innovative educational game using robotics technology aims to improve students' understanding of the concept of straight motion. The two main aspects considered are software and hardware. For software, the Corel Draw X8 application was used as a tool to design the trajectory design of the line follower robot according to the concept of Regular Straight Motion (GLB) and Regularly Changing Straight Motion (GLBB) material. In addition, the Chios program was chosen as the platform to run the line follower robot, enabling efficient and responsive use in testing the developed educational game. Meanwhile, in the hardware aspect, the required components include PCB as the robot frame, other supporting components, as well as the Atmega 1284 P DIP IC as the brain of the robot that will be filled with the Chios program. The main drive of this robot consists of two motors, with power supported by a battery type Battery Lypo Nano Tech 850 mAh 3 s/11.1 V. This combination of software and hardware provides a solid foundation for the development of media that can integrate physics learning concepts with robotics technology in an interactive and informative way.

A. *Game-D Development*

In the Game-D development stage, the process of making learning media in the form of educational games using line follower robots is carried out. Some of the stages required in this process include selecting appropriate material content for educational games using line follower robots, collecting sources and references that will be used in the development of these media, searching and collecting components of tools and materials for making line follower robots, and making line follower robot track designs that must be in accordance with the concept of the material that will be contained in the game. Fig. 2 illustrates the design of the line follower robot track that will be used in the game. In addition, at this stage, a guidebook module is also made that explains how to use the line follower robot in the context of the educational game. Fig. 2 presents these stages as an important foundation in the process of developing interactive and informative media in integrating the concept of straight motion with robotics technology for educational purposes.

Game-D is an educational game development framework that integrates line-following robot technology for straight-line motion materials. The complex development process of Game-D involves a series of detailed stages, starting from conception to implementation. One of the key stages in the development of the Game-D is the process of creating learning media in the form of educational games, which are packaged interactively by utilizing the capabilities and functionality of the line follower robot. Fig. 3 presents the Game-D development framework.

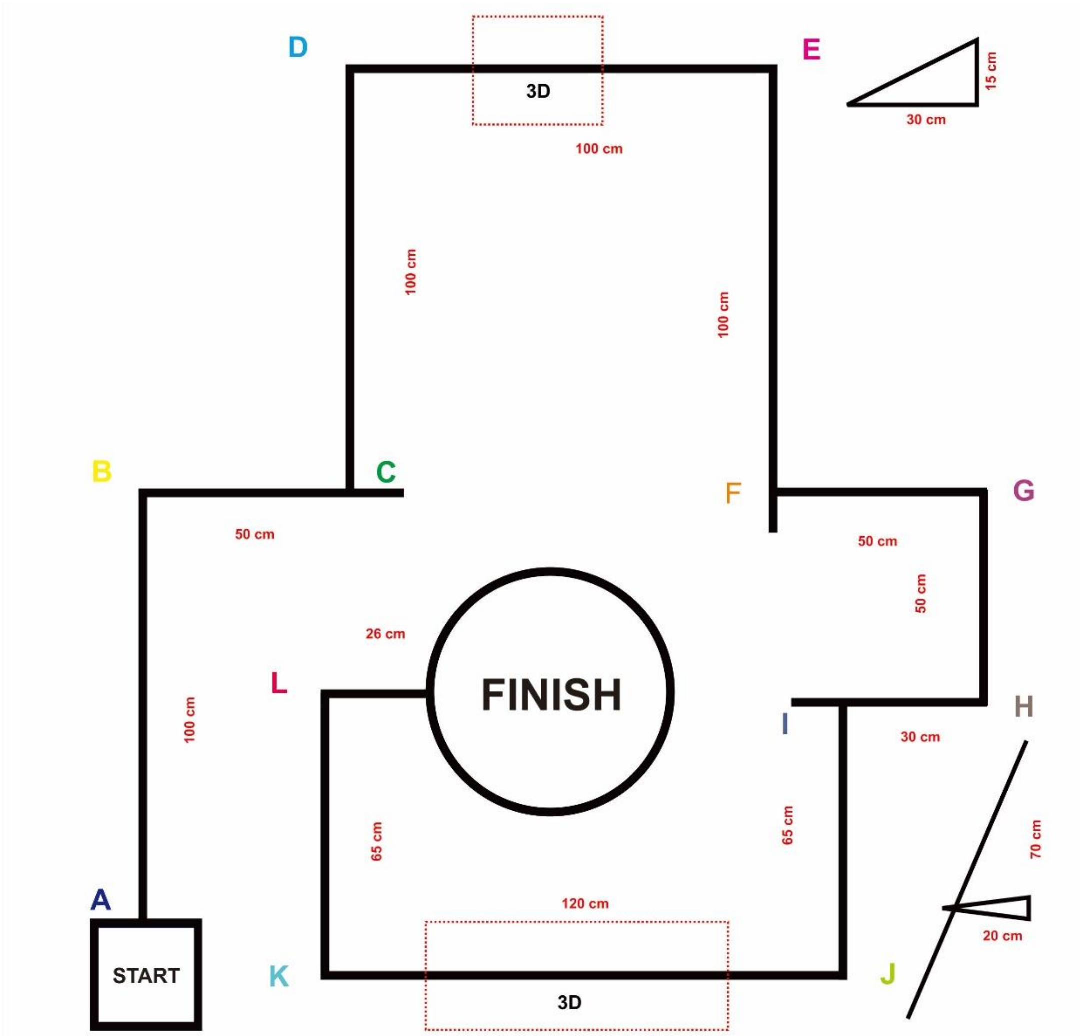

Fig. 2. Trajectory design of the line follower robot.

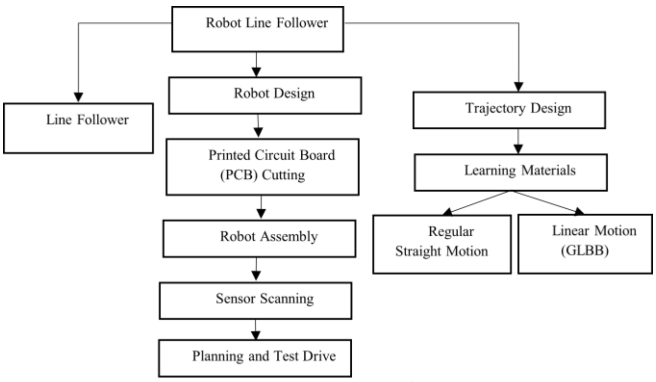

Fig. 3. Game-D development framework.

Game-D is an educational game development project that integrates line follower robot technology for straight motion materials. The robot is designed to follow a path automatically using sensors mounted on its underside, enabling precise and accurate navigation. In Game-D, users are invited to utilize this line follower robot in various educational challenges related to straight motion. Through interaction with this robot, users will learn basic concepts about straight motion, such as acceleration, velocity, and distance. In addition, the interactive features and challenges in the game ensure that users are actively involved in the learning process. Thus, Game-D is not only a fun game, but also an effective learning tool to understand the concept of straight motion in a practical way. The following is the design of the Gama-D robot using the Chios program presented in Fig. 4 below:

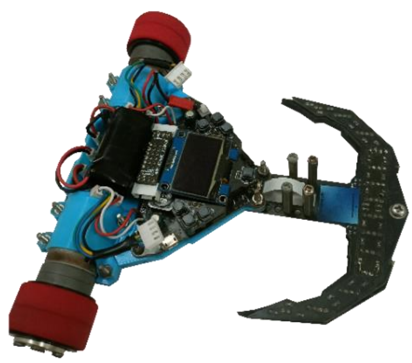

Fig. 4. Game-D robot.

B. Research Results

Media validity analysis in the context of the Game-D project is very important to measure the validity of media to develop educational games that integrate robotics technology in education. The validity test results show that in the Software Engineering Component aspect, the goal is to ensure the validity and practicality of the game in providing a consistent learning experience. Meanwhile, the Game-D Practicality Analysis was developed to evaluate three main aspects: ease of use, media benefits, and game elements. This instrument was designed to assess the practicality of the educational game, Game-D, through a structured questionnaire administered to lecturers and students. The questionnaire was designed to obtain detailed feedback regarding the user experience. The results of the media validity and practicality test and are presented in Table 7.

Table 7. Results of fulfillment and practicality test of media

Assessment Aspect	Validity				Assessment Aspect	Practicality (%)	Assessment criteria
	Validator I (%)	Validator II (%)	Average (%)	Assessment criteria			
Aspects of Software Engineering Components	100	75	87.5	Very valid	Ease of use	85.71	Very practical
Visual Communication Component	75	100	87.5	Very valid	Media benefits	85.71	Very practical
Graphics Component	100	75	87.5	Very valid	Game elements	85.71	Very practical
Average	91.67	83.33	87.5	Very valid	Average (%)	85.71	Very practical

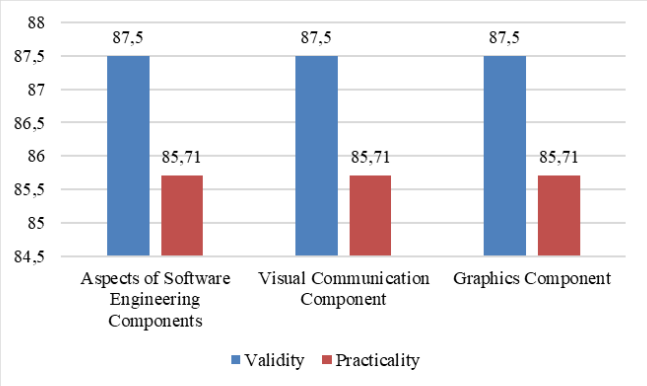

Fig. 5. Results of validity and practicality test analysis of Game-D media.

The analysis results in Table 7 show that the media validity analysis test on the aspects of Software Engineering Components obtained a value of 87.5%, categorized as very valid. The Visual Communication Component aspect also obtained a value of 87.5%, categorized as very valid, and the Graphics Component aspect received a value of 87.5%, categorized as very valid. Meanwhile, the media practicality test revealed that the Ease-of-Use aspect obtained a value of 85.71%, categorized as very practical. The Media Benefits aspect also obtained a value of 85.71%, categorized as very practical, and the Game Elements aspect received a value of 85.71%, categorized as very practical. Thus, the average validity value obtained is 87.5%, classified as very valid, while the media practicality value reaches 85.71%, classified as very practical. These validity and practicality test results indicate the significant potential of this game in creating an effective and satisfying learning experience for users. The analyzed data is presented in Fig. 5.

The materials expert validity Analysis of the development of the "Game-D" is an important step to ensure the suitability of the delivered materials to the teaching targets. In this instrument, three key aspects were evaluated: material validity aspect, linguistic aspect, and display aspect. First, the material appropriateness aspect assesses the relevance, depth, and clarity of the material presented in the game to the applicable educational curriculum. Second, the linguistic aspect evaluates the clarity of the language used, the readability of the text, and the appropriateness of the language level to the target audience, ensuring that the educational message is conveyed effectively. Finally, the display aspect assesses the visual presentation of the material, including interface design and visual clarity, to ensure a pleasant and easy-to-understand user experience. Data from the validity analysis of material experts is presented in Table 8.

Table 8. Results of fulfillment and practicality test of material

Assessment Aspect	Validity				Assessment Aspect	Practicality (%)	Assessment criteria
	Validator I (%)	Validator II (%)	Average (%)	Assessment criteria			
Aspects of the material validity component	87.5	87.5	87.5	Very valid	Ease of use	85.71	Very practical
Aspects of linguistic components	91.67	91.67	91.67	Very valid	Media benefits	90.48	Very practical
Display aspect	75	100	87.5	Very valid	Game elements	85.71	Very practical
Average (%)	84.72	93.06	88.89	Very valid	Average (%)	87.3	Very practical

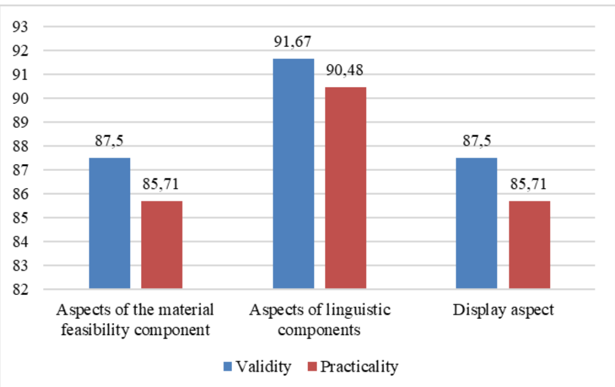

Fig. 6. Results of validity and practicality test analysis of Game-D material.

Based on the data analyzed in Table 8, the media validity analysis test on the Software Engineering Component aspect obtained a value of 87.5%, categorized as very valid. The Visual Communication Component aspect received a value of 91.67%, categorized as very valid, and the Graphics Component aspect obtained a value of 87.5%, also categorized as very valid. Meanwhile, the media practicality test revealed that the Ease-of-Use aspect received a value of 85.71%, categorized as very practical. The Media Benefits aspect received a value of 90.48%, categorized as very practical, and the Game Elements aspect obtained a value of 85.71%, categorized as very practical. Overall, the average validity score reached 88.89%, indicating excellent validity. Meanwhile, the practicality of the material reached 87.3%, indicating a very high level of practicality. Fig. 6 presents the results of the validity and practicality analysis by material experts. The validity analysis by material experts provides an overall view to ensure that the educational game is not only engaging but also effective in conveying educational concepts to users. The material validity in the development of Game-D is a crucial step to ensure the alignment of the delivered material with the learning objectives.

From the results of the validity and practicality tests obtained from media experts and material experts, the overall average validation and practicality data for the development of educational games using line-following robots on straight motion material were obtained. the results of the analysis of the average validity and practicality tests are presented in Table 9.

Based on Table 9, it can be concluded that the D-Game development project successfully achieved its objectives. Through media and material validity tests, as well as practicality analysis, it was found that the game met high standards in terms of validity and practicality. With an average validity score of 88.2% and a practicality score of 86.5%, the game is deemed highly valid and practical as a learning medium for straight-line motion. These results confirm that the use of line-following robots in the context of educational games can enhance the quality of learning, making it a viable tool to support the educational process. Thus, the development of the educational game named Game-D demonstrates significant potential to improve learning effectiveness in terms of media validity and practicality, providing an engaging and beneficial learning experience for users.

Table 9. Average results of validity and practicality test of Game-D

No.	Experts	Validity (%)	Aspect	Practicality (%)
1.	Media Expert	87.5	Ease of use, Media benefits, Game elements	85.71
2.	Material Expert	88.89		87.3
Average		88.2	Average	86.5
Assessment criteria		Very valid	Assessment criteria	Very practical

The effectiveness analysis results of the Game-D development, aimed at evaluating the responses and perceptions of students from the Science Education Department, Faculty of Teacher Training and Education, Universitas Trunojoyo Madura, have been obtained. This effectiveness questionnaire includes aspects such as understanding of the material concepts, active engagement in the game, and student motivation levels. Table 10 presents the data from this analysis, which is expected to provide valuable insights into the effectiveness of using an educational game with a line-following robot for straight-line motion material in achieving the established learning objectives, as well as the level of student satisfaction with the learning experience provided.

Based on the results of the media effectiveness test, it can be concluded that the development of Game-D has a highly effective impact on various aspects of learning. The effectiveness score for concept understanding was 86.04%, while active engagement in learning scored 87.12%, and the increase in learning motivation scored 85.60%. With an overall average media effectiveness score of 86.25%, it can be concluded that this game significantly enhances concept understanding, promotes active engagement in learning, and boosts user motivation. This underscores that Game-D is a highly effective tool for supporting the learning process of straight-line motion material using a line follower robot.

Table 10. Effectiveness analysis results

No.	Assessment Aspect	Assessment Result (%)	Average (%)	Category
1.	Conceptual understanding of the material	85.42 87.50 85.83 85.42	86.04	Very effective
2.	Active involvement in learning	85.33 87.42 88.83 86.92	87.12	Very effective
3.	Increased learning motivation	85.00 85.42 84.92 87.08	85.60	Very effective
Average			86.25	Very effective

C. Discussion

Game-D introduces an innovative method of blending educational gaming with robotics technology to facilitate learning about straight motion concepts. This section explores the implications, limitations, and future directions of the educational game based on its development and implementation. The findings from this study align with existing literature on the benefits of integrating educational games with robotics. As highlighted by prior research [35, 36], one of the key strengths of educational games is their ability to actively engage students in the learning process by combining interactive game elements with hands-on robotics experiences. This approach promotes experiential learning and encourages exploration of physics of motion concepts in a way that traditional methods may not. The results of the analysis demonstrated that Game-D met high standards of validity and reliability, with an average validity score of 88.25% (categorized as very valid) and a practicality score of 87.3% (categorized as very practical). Additionally, the effectiveness test yielded a high score of 86.25% (categorized as highly effective). These findings suggest that Game-D is not only a valid and practical educational tool but also highly effective in enhancing students' understanding of straight motion concepts. This corroborates the research findings by other scholars [19, 37] which assert that integrating robots into educational games can significantly improve the quality of learning, providing a viable tool to support the educational process. One of the most notable outcomes of implementing Game-D was the significant improvement in students' conceptual understanding, active engagement, and motivation to learn. Guided by constructivist pedagogical principles [38, 39] Game-D emphasizes active learning, problem-solving, and inquiry-based approaches. This aligns with theories of experiential learning where students construct knowledge through direct interaction with learning materials. Despite the promising results, this study has several limitations that need to be acknowledged. Firstly, the sample size was relatively small and confined to a specific educational setting, which may limit the generalizability of the findings. Larger-scale studies across diverse educational environments are needed to confirm the results. Secondly, while the feedback from educators and students was positive, there were some technical challenges reported during the implementation phase. Issues related to the hardware and software integration of the line-following robot and the game interface occasionally disrupted the learning experience.

Future iterations of Game-D will need to address these technical challenges to ensure a seamless integration of technology in educational settings. Future research should focus on exploring additional pedagogical strategies that could be incorporated into Game-D to optimize learning outcomes. This could include adaptive learning paths that cater to individual student's learning paces and styles, as well as incorporating more complex physics concepts beyond straight motion. Moreover, extending the research to different educational settings and larger sample sizes will help validate the effectiveness of Game-D across various contexts. It would also be beneficial to investigate the long-term impact of using Game-D on students' overall academic performance and interest in STEM fields.

Overall, Game-D holds significant promise for integrating educational gaming and robotics technology to foster dynamic and interactive learning experiences [40, 41]. The study's findings indicate that Game-D is a highly valid, practical, and effective tool for teaching straight motion concepts. However, continued research and iterative improvements are necessary to refine its effectiveness and address any technical challenges, ensuring it can be successfully implemented across diverse educational settings. The potential of Game-D to enhance STEM education is substantial, and with ongoing development, it could become a cornerstone in modern educational practices.

V. Conclusions

The development and implementation of Game-D represent a significant advancement in the realm of educational gaming and robotics technology. Through the integration of a line follower robot and interactive gaming elements, Game-D offers a unique platform for teaching and learning straight motion material in an engaging and immersive manner. The synthesis of educational gaming principles with robotics technology in Game-D has several notable implications for educational practice. Firstly, the game fosters active learning by providing students with opportunities to apply theoretical concepts in a practical, hands-on context. This active engagement promotes deeper understanding and retention of straight motion principles, as evidenced by the positive learning outcomes observed in evaluation studies. Furthermore, Game-D serves as a catalyst for enhancing student motivation and interest in STEM subjects. By leveraging gamification elements such as challenges, rewards, and competition, Game-D stimulates intrinsic motivation and encourages students to explore and experiment with motion physics concepts in a supportive learning environment. Moreover, the iterative design process employed in the development of Game-D underscores the importance of pedagogical considerations and user feedback in creating effective educational games. By incorporating input from educators and students throughout the design process, Game-D has been refined to align closely with educational objectives and user preferences, thereby enhancing its efficacy as a teaching tool. Going forward, future research efforts should focus on further evaluating the long-term impact of educational games on students' learning outcomes and their attitudes towards STEM disciplines. In addition, efforts to expand the scope of Game-D to cover a wider range of physics concepts and educational levels will contribute to its versatility and applicability in various educational environments. In summary, Game-D represents a promising avenue for advancing the integration of educational gaming and robotics technology in teaching straight motion material. By providing a dynamic and interactive learning experience, Game-D has the potential to inspire and empower students to explore the fascinating world of physics and robotics while cultivating essential skills for success in the 21st century.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Fivia Eliza: Conceptualization; methodology; project administration; writing-original draft; writing- review and editing. Muhammad Hakiki: methodology; project administration; writing-original draft; writing- review and editing. Mughnil Muhtaj: Software; project administration; visualization. Della Asmaria Putri: Formal analysis; Data curation; visualization. Yayuk Hidayah: Formal analysis; validation; supervision. Ade Fricticarani: Investigation; resources. Jamal Fakhri: Investigation; resources. Iqbal Arpannudin: Data curation; formal analysis; writing - review and editing. Kelik Sussolaikah: Software; project administration; visualization. Mustofa Abi Hamid: Formal analysis; validation; supervision. Radinal Fadli: Formal analysis; validation; supervision. M. Agphin Ramadhan: Formal analysis; validation; supervision. All authors had approved the final version.

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