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PAPER

Gamification: Enhancing Constructivist Skills through Line-Following Robots

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ABSTRACT

This study addresses the challenge of enhancing student engagement and constructivist skills in engineering education by integrating gamification with line-following robots. The problem arises from the need for more interactive and engaging learning experiences in technical disciplines, where traditional methods often fail to actively involve students in the learning process. To tackle this challenge, the study explores how gamification, using game design elements in non-game contexts, can motivate students and create a more dynamic learning environment. The main objective is to investigate the effectiveness of this approach in promoting student engagement, motivation to learn, critical thinking skills, problem solving, and student collaboration, which are all core elements of the constructivist learning theory. The research employs the analysis, design, development, implementation, and evaluation (ADDIE) model as a framework, using a quantitative research design to evaluate both validity and practicality. The study was conducted at the Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Yogyakarta, Indonesia. Data collection involved expert validation from media and gamification specialists, with the average validity scores of 0.90 and 0.89, indicating a highly valid approach. Practicality assessments from educators yielded an average score of 91.85%, while student feedback showed an effectiveness rating of 90.62%. These results highlight the significant potential of combining gamification with robotics to enhance constructivist skills in an engineering education context. Future research should investigate the long-term effects of this integration and explore its applicability across broader educational environments and age groups.

KEYWORDS

gamification, constructivist skills, line-following robots, model analysis, design, development, implementation, and evaluation (ADDIE)

1 INTRODUCTION

Rapid technological advances have led to a significant transformation in the educational landscape, offering innovative opportunities to improve student engagement, motivation, and learning outcomes [1], [2]. Research [3] explains one area of

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growing interest is the integration of gamification, which is defined as the use of game design elements in non-game contexts in educational environments. In line with research [4], it explains that gamification can enhance the learning experience by making it more interactive, fun, and engaging for students. However, while the motivational benefits of gamification have been well documented, there is still limited research regarding how gamification can be effectively combined with other technologies, such as robotics, to foster constructivist learning [5], [6]. This gap in the literature highlights the need for further exploration of how gamification and robotics can be integrated to encourage critical thinking, problem solving, and collaboration, which are core principles of constructivist pedagogy.

In addition to gamification, constructivist learning theory emphasizes the importance of active, hands-on experiences where students can construct their own knowledge through exploration and experimentation [7]. Research [8] explains this approach contrasts with traditional didactic teaching methods by focusing on student-centered activities that promote deeper understanding through real-world problem-solving. Robots, particularly line-following robots equipped with sensors to detect and navigate pre-set paths, offer a unique opportunity to bring constructivist principles to life [9]. These robotic systems can simulate real-world scenarios and challenge students to engage in critical thinking and collaborative problem-solving, aligning well with the goals of constructivist learning [10].

Research [11] describes line-following robots, which are equipped with sensors to detect and follow predetermined paths, offer a versatile platform for designing educational activities. These robots can be programmed to navigate complex routes, simulate real-world scenarios, and interact with students in a variety of ways [12], [13]. By incorporating these robotic systems into classroom settings, lecturers can create immersive learning experiences that not only hold students' interest but also foster important skills such as critical thinking, problem-solving, and teamwork [14], [15].

The present study seeks to address the gap in the literature by evaluating the practical application of gamification combined with line-following robots in enhancing constructivist skills among engineering students. The focus of this study is to validate the practicality and effectiveness of the gamification approach in fostering critical skills such as student engagement, learning motivation, critical thinking skills, problem solving, and student collaboration, as perceived by educators and students. This study objective is reinforced by research [16], [17], which explains that gamification offers valuable insights in the development of innovative educational strategies that utilize gamification and robotics to support constructivist learning environments.

The objectives of this study are twofold: (1) to assess the validity of gamification integrated with line-following robots as a tool for enhancing constructivist skills, based on expert evaluations, and (2) to evaluate the practicality and effectiveness of this approach from the perspective of both educators and students. These objectives are aligned with the current study's focus on validation and practicality, rather than claiming improvements in creative thinking or the effectiveness of specific instructional methods. To guide the investigation, the following research questions are proposed:

1. How can the integration of gamification with line-following robots improve students' constructivist skills?
2. To what extent do media and gamification experts perceive the validity of gamification in enhancing constructivist skills using line-following robots in an engineering education environment?

3. To what extent do faculty perceive the practicality of gamification in enhancing constructivist skills using a line-follower robot in an engineering education environment?
4. How effective is the line-follower robot in enhancing students' constructivist skills?

2 LITERATURE REVIEW

Gamification, the integration of game design elements into non-game contexts, has become a significant area of interest in educational research. It is defined as the application of game mechanics such as points, badges, and leaderboards to non-game activities to increase motivation and engagement [18]. Recent studies have demonstrated that gamification can enhance learning outcomes by making educational activities more engaging and interactive [19], [20]. For instance, gamified learning environments have been shown to improve student motivation, increase participation, and facilitate a more enjoyable learning experience [21]. The use of gamification in educational settings aligns with theories of intrinsic motivation, which suggest that when students find learning activities enjoyable and rewarding, their engagement and persistence improve [22].

Constructivist learning theory, originally articulated by Piaget (1952) and Vygotsky (1978), posits that learners construct knowledge through active engagement and interaction with their environment. Constructivist pedagogy emphasizes the importance of experiential learning, where students engage in hands-on activities, explore concepts, and collaborate with peers to build understanding [23]. According to this theory, learning is an active process where students are encouraged to experiment, reflect, and develop problem-solving skills through meaningful experiences [24]. The role of the lecturer in a constructivist classroom is to facilitate and guide rather than to directly impart knowledge, thereby promoting a student-centered learning environment [25].

The integration of robotics into educational contexts has gained traction as a means of supporting constructivist learning principles. Robotics provides a tangible, interactive medium through which students can engage in complex problem-solving tasks and develop technical skills [26]. Line-following robots, specifically, are used as educational tools to teach programming, logic, and problem-solving in an accessible and engaging manner [27]. Studies have shown that robotics can enhance student learning by providing a hands-on approach to understanding abstract concepts and by fostering collaborative learning experiences [28]. The use of robotics in education aligns with constructivist principles by encouraging active exploration, experimentation, and iterative learning processes [29].

Research [30] explains that combining gamification with robotics is a new approach to improving educational outcomes. This is supported by research [31], which explains that the use of line-following robot gamification can create an interactive and motivating learning environment. By incorporating game elements such as challenges, rewards, and progress into robotics activities, lecturers can leverage the benefits of both gamification and constructivist learning [32]. This synergy has the potential to increase student engagement, learning motivation, critical thinking skills, problem solving, and collaboration among students, in line with the goals of constructivist pedagogy [33]. Research [34] shows that an integrated approach with educational games can increase student engagement, improve problem-solving skills, and deeper understanding of complex concepts.

The literature suggests that gamification and robotics have the potential to enhance the educational experience by increasing engagement and supporting constructivist learning principles. Gamification can make learning activities more engaging and fun, while robotics provides a hands-on platform for developing technical and problem-solving skills. The combination of these elements in an educational environment offers a promising approach to improving constructivist skills such as student engagement, learning motivation, critical thinking skills, problem solving, and collaboration. Further research is needed to explore the effectiveness of this integrated approach and its impact on various educational outcomes.

3 METHODOLOGY

This study methodology uses a research and development (R&D) approach using the analysis, design, development, implementation, and evaluation (ADDIE) model, a systematic framework designed to guide the creation and evaluation of educational tools and strategies [35]. This structured methodology allows for continuous refinement and optimization of educational strategies, ensuring that the final product produced has a sound pedagogical basis and is practically effective in improving student learning outcomes [36].

3.1 Research design

This study employed the ADDIE model, a widely recognized instructional design framework, to systematically guide the research process [37]. Figure 1 presents the ADDIE development procedure.

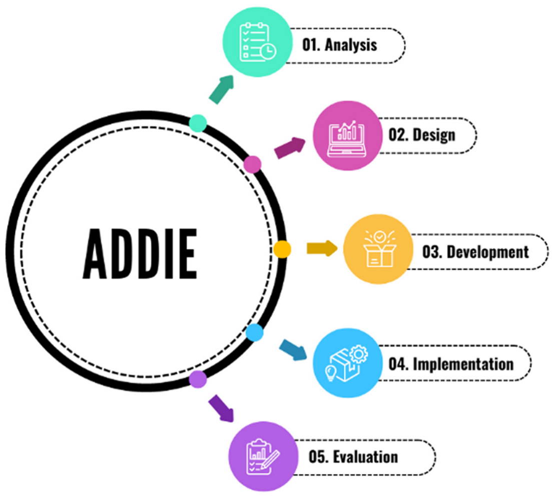


Fig. 1. Development procedure

The ADDIE model provided a structured approach to developing and assessing the effectiveness of gamified educational activities using line-following robots to enhance constructivist skills. Each phase of the ADDIE model is detailed below.

Analysis. In the analysis phase, the study identified key educational needs and learning outcomes by conducting a comprehensive literature review on gamification, constructivist learning, and robotics in education, aiming to evaluate their potential in enhancing critical thinking, creativity, and collaboration. Consultations with lecturers and curriculum developers in the electronics engineering department revealed gaps in current teaching methodologies and highlighted the specific skills that students needed to develop. This phase led to the formulation of primary research questions focusing on how gamification, using line-following robots, can effectively enhance constructivist skills and be integrated into existing curricula to optimize learning outcomes.

Design. In the design phase, the study conceptualized the structure of gamified learning activities centered on line-following robots, with the goal of creating engaging, interactive tasks that allowed students to apply theoretical concepts in a practical, hands-on setting. Utilizing Corel Draw X8, the tracks for the robots were meticulously designed to align with the learning objectives identified in the analysis phase. The activities were crafted to incorporate essential elements of gamification, including progressively challenging tasks that promoted higher-order thinking, immediate feedback through robot responses, and collaborative tasks that fostered teamwork and communication. The anticipated outcomes were enhanced student abilities in critical thinking, creative problem-solving, and effective teamwork.

Development. In the development phase, the study transformed the conceptual designs into tangible educational tools and materials, programming line-following robots using the Chios platform with the Atmega 1284P microcontroller as the central processing unit. Hardware components such as the PCB, motors, and battery were assembled to create fully functional robots. Gamified activities were designed to replicate real-world scenarios, challenging students to navigate complex tracks in line with the educational objectives. Pilot testing was conducted to validate the functionality of both the hardware and software, with subsequent adjustments made to optimize performance and enhance the overall learning experience.

Implementation. In the implementation phase, the developed gamification activity was implemented in an actual classroom setting at the Electrical Engineering Department, Faculty of Engineering, Universitas Negeri Yogyakarta, Indonesia. The study involved students enrolled in a robotics course, with the implementation conducted over several sessions where students engaged with the robot following a line and participating in designed tasks. The lecturers received two months of training to effectively facilitate this activity and integrate it into the wider curriculum. During this phase, students' interactions with the robot were monitored during one semester of lectures, data on their performance was collected, and the development of constructivist skills was observed to assess the effectiveness of the implementation.

Evaluation. In the evaluation stage, the effectiveness of the gamification activities was assessed through both formative and summative methods. Formative evaluation involved continuous feedback from students and lecturers during the implementation phase, enabling real-time adjustments to enhance the learning experience. Summative evaluation, conducted at the study's conclusion, utilized a combination of quantitative and qualitative data, including baseline and final tests to measure improvements in student engagement, learning motivation, critical thinking, problem-solving, collaboration, ease of use, and the usability of the line-following robots, as well as constructivist skills. Additionally, questionnaire analysis captured lecturers' experiences and perceptions regarding ease of use, motivational impact on teaching, robot usability, learning efficiency, problem-solving, collaboration, and constructivist skills. The findings demonstrated significant improvements in constructivist skills, affirming the effectiveness of the ADDIE model in developing and implementing innovative educational strategies that integrate gamification and robotics.

The use of the ADDIE model in this study provided a systematic approach to developing and evaluating gamified educational activities. The structured phases ensured that each aspect of the project was aligned with the research objectives, resulting in a successful integration of gamification and line-following robots into the educational process. The positive outcomes underscore the potential of this approach to enhance constructivist skills and offer valuable insights for future educational innovations.

3.2 Research participants

This study was conducted at the Department of Electrical Engineering Education, Faculty of Engineering, Yogyakarta State University, Indonesia. The study involved a purposive sample of students enrolled in robotics courses in the department, consisting of 60 students [38]. These students participated in a series of game-based educational activities designed to enhance their constructivist skills, including critical thinking, problem solving, and collaboration. The selection of this sample was based on their familiarity with the subject matter and their potential to benefit from the integration of gamification and robotics into the curriculum. 10 lecturers from the same department also participated in the study, who contributed to the implementation and evaluation of gamification educational activities. The sample size was chosen to ensure a comprehensive analysis of the effectiveness of integrating gamification and robotics into the educational environment.

3.3 Research instruments

Validity instruments. The media expert validity instrument is designed to assess various aspects of educational media, mainly focusing on its relevance, accuracy, usability, and effectiveness in enhancing constructivist skills. The instrument was developed to collect expert evaluations from media and gamification validators to ensure that the educational media, in this case, a line-following robot used in a gamified learning environment, meets the standards required for effective teaching and learning. The media expert validity instrument is presented in Table 1.

Table 1. Media expert validity instrument

No.	Instrument
1	Relevance and Appropriateness to Learning Objectives
2	Accuracy, Validity, and Reliability of Information
3	Effectiveness in Conceptual Understanding
4	Clarity of Language and Visuals
5	Support for Learning Principles through Visual Design
6	Interactivity and Student Involvement
7	Suitability for Student Profiles
8	Ease of Use for Lecturers
9	Flexibility in Different Learning Contexts
10	Compatibility with Available Technology
11	Compliance with Curriculum Standards
12	Effectiveness in Enhancing Constructivist Skills
13	Long-Term Reliability and Usability

The gamification expert validity instrument was developed to assess the effectiveness and appropriateness of gamification elements in educational environments, particularly in enhancing constructivist skills such as student engagement, motivation to learn, critical thinking, problem solving, and collaboration. The instrument asks for expert evaluation to ensure that the gamification design is aligned with educational objectives and supports the development of essential skills in students. The gamification expert validity instrument is presented in Table 2.

Table 2. Gamification expert validity instrument

No.	Instrument
1	Clarity of Gamification Objectives
2	Alignment with Educational Objectives
3	Effectiveness in Student Engagement
4	Motivation to Learn
5	Challenge Appropriateness
6	Effectiveness of Feedback Mechanisms
7	User-Friendliness and Accessibility
8	Promotion of Collaboration and Teamwork
9	Encouragement of Critical Thinking and Problem-Solving
10	Fostering Creativity and Innovation
11	Alignment with Constructivist Learning Principles
12	Contribution to Educational Outcomes
13	Adaptability and Flexibility

Practicality and effectiveness instruments. Practicality instruments for lecturer responses and an effectiveness instrument for student responses to constructivist skills have been carefully crafted to evaluate the usability and effectiveness of a gamified learning activity involving a line-following robot. These instruments aim to gather insights on learning engagement, motivation to learn, critical thinking, problem solving, collaboration, and constructivist skills from the perspectives of lecturers and students. By analyzing the responses, the research seeks to determine how well this gamification activity integrates into the existing curriculum and enhances the learning experience. The feedback provided will provide important data for refining the educational strategy, ensuring that it is practical and impactful in fostering constructivist skills in diverse educational contexts. Instruments for practicality from lecturer responses and effectiveness from student responses are presented in Tables 3 and 4.

Table 3. Indicators of lecturer response practicality instruments

Indicator	Item
Lecturer engagement	1, 2, 3, 4, 5, 6
Teaching Motivation	7, 8, 9, 10, 11, 12
Critical thinking	13, 14, 15, 16, 17, 18
Problem-solving	19, 20, 21, 22, 23, 24
Collaboration	25, 26, 27, 28, 29, 30

Table 4. Indicators of student response effectiveness instruments

Indicator	Item
Student engagement	1, 2, 3, 4, 5, 6
Learning motivation	7, 8, 9, 10, 11, 12
Critical thinking	13, 14, 15, 16, 17, 18
Problem-solving	19, 20, 21, 22, 23, 24
Collaboration	25, 26, 27, 28, 29, 30
Constructivist skills	31, 32, 33, 34, 35, 36

3.4 Data analysis technique

Validity analysis technique. The data analysis technique for testing the validity of media experts and gamification in this study uses the formula:

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

where V represents the validity coefficient, $\sum S$ is the sum of the scores provided by the expert validators, n is the number of validators, and c is the number of possible score categories. This method is used to quantitatively assess the validity of the educational tools and gamification elements designed for the study. The resulting validity coefficient is then categorized to determine the level of validity, as outlined in Table 5 below:

Table 5. Categorize the validity of gamification

Validity Coefficient (V)	Validity Category
0.81–1.00	Very Valid
0.61–0.80	Valid
0.41–0.60	Fairly Valid
0.21–0.40	Less Valid
0.00–0.20	Not Valid

The analysis categorizes the validity coefficient to evaluate whether the instruments meet the required educational standards. A validity coefficient within the range of 0.81–1.00 is considered "Very Valid," indicating that the tools are highly aligned with the study's educational objectives. This comprehensive approach ensures that the instruments used in the research are reliable and suitable for achieving the intended outcomes.

3.5 Practicality and effectiveness analysis technique

The technique for analyzing the practicality and effectiveness of the effectiveness instrument for student responses to improving constructivist skills in this study uses the formula:

$$NA = \frac{S}{M} \times 100\% \tag{2}$$

where *NA* represents the percentage of practicality and effectiveness, *S* is the total score achieved for the practicality and effectiveness aspects, and *M* is the maximum possible score. This formula measures the extent to which educational aids and activities are practical, based on feedback from educators and students. The resulting practicality and effectiveness percentages are categorized to assess the effectiveness and usefulness of the aids, as detailed in Table 6 below:

Table 6. Categorize the practicality and effectiveness of educational game media

Category Percentage Practicality and Effectiveness (NA)	Category Practicality and Effectiveness
90%–100%	Highly practical and effective
70%–89%	Practical and effective
50%–69%	Moderately practical and effective
30%–49%	Slightly practical and effective
Below 30%	Not practical and effective

This categorization provides a clear framework for interpreting the practicality and effectiveness scores, ensuring that educational tools and activities are comprehensively evaluated. Practicality and effectiveness percentages in the 90%–100% range indicate that the tool is "Highly Practical and effective," indicating strong functionality and user satisfaction. This approach facilitated a thorough assessment of the tool's effectiveness, supporting the study's aim to provide effective and easy-to-use educational solutions.

4 RESULT AND DISCUSSION

4.1 Development

The development phase of the project focused on creating an integrated hardware and software system to support the gamification of educational activities using line-following robots. This section details the design and implementation of the system, covering both the software and hardware components utilized.

Software development. For the software aspect, Corel-Draw X_{12} was used as the main tool for designing the robot trajectory layout. This software was chosen for its precision and ease of use, allowing the creation of detailed and accurate trajectory designs. This design is essential for the robotics course in the electronics engineering department, which provides a clear and consistent path for students to navigate the line-following robot. Figure 2 presents the robot trajectory design.

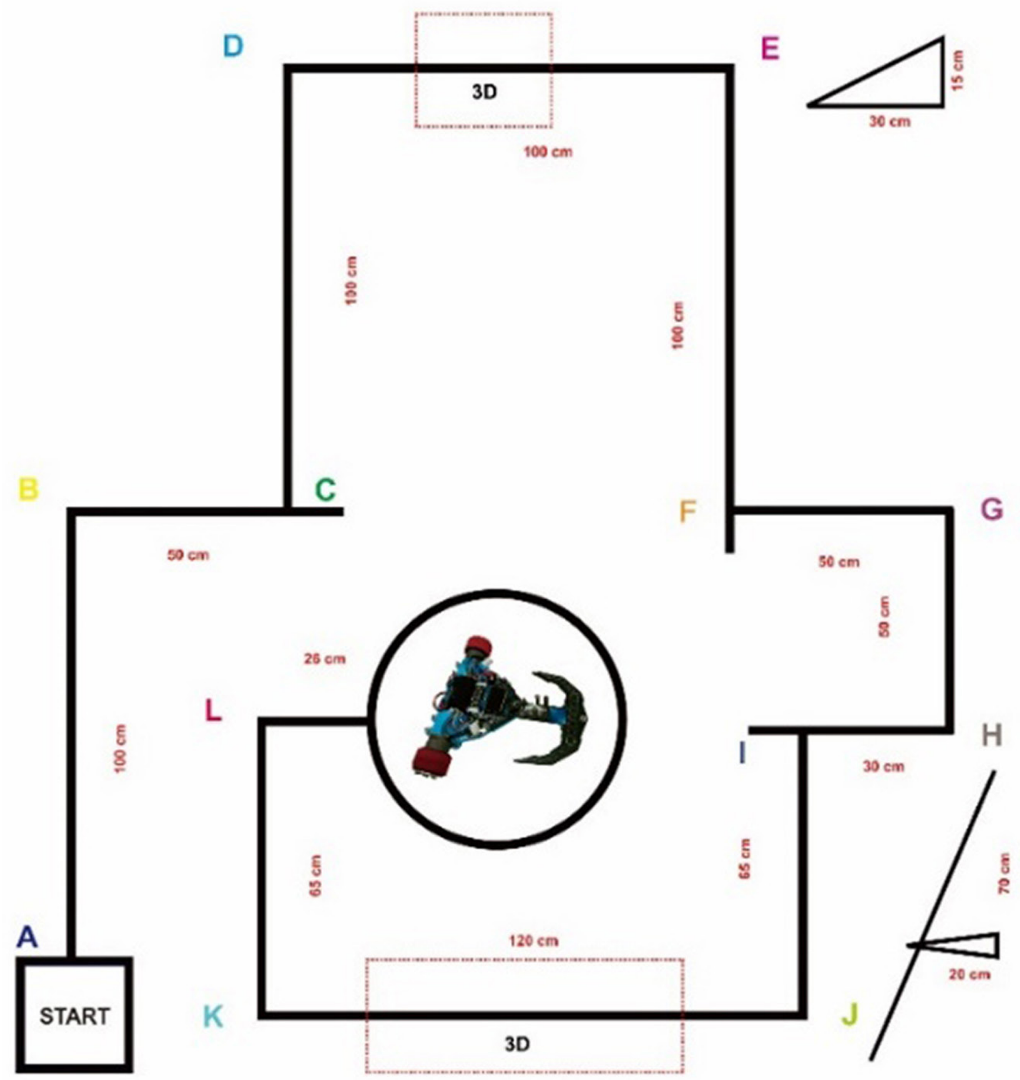


Fig. 2. Robot trajectory design

In addition to the design software, Chios, a powerful programming platform, was chosen to control the line-following robot. Chios was chosen for its efficiency and responsiveness, which is essential for real-time testing of educational games. The flexibility of this platform allows the development of various game scenarios and challenges, thus enabling a dynamic and engaging learning experience. The use of Chios also facilitates easy programming and debugging, making it accessible to lecturers and students.

Hardware development. The hardware configuration of the line follower robot is carefully selected to ensure optimal performance and reliability. The core structural component, a custom-designed printed circuit board (PCB), serves as the robot's chassis. This PCB houses the necessary electronic components and provides a stable foundation for the entire system. Key hardware components include the Atmega 1284P DIP IC, which acts as the robot's microcontroller. This microcontroller is programmed using the Chios platform and is responsible for processing inputs from sensors and executing programmed instructions. The Atmega 1284P was chosen for its processing power and compatibility with the Chios programming environment. The movement of the robot is powered by two DC motors, which are precisely controlled to ensure accurate navigation along the designed track. These motors are driven by motor drivers connected to the microcontroller, thus allowing precise control over speed and direction. To power the entire system, a Lypo Nano Tech 850 mAh 3s/11.1V battery is used, chosen for its high energy density and light weight, which provides enough power for long periods of operation without significantly increasing the weight of the robot. This battery configuration ensures that the robot can work consistently during prolonged educational sessions, making it a reliable tool for classroom use.

Integration and testing. Integration of hardware and software components is an important phase in the development process. Rigorous testing is conducted to ensure that the robot can accurately follow the designed path and respond appropriately to the programmed challenges. The testing phase involves troubleshooting and optimizing the robot's performance, ensuring that the hardware and software work seamlessly. Figure 3 presents the testing of the line follower robot.

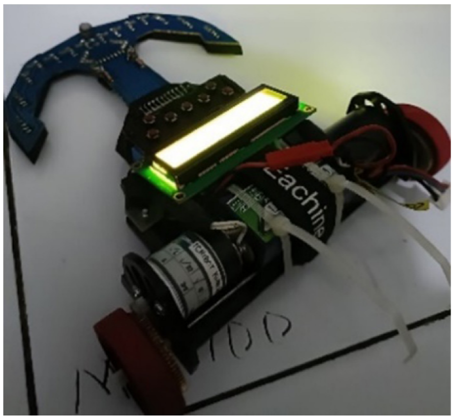
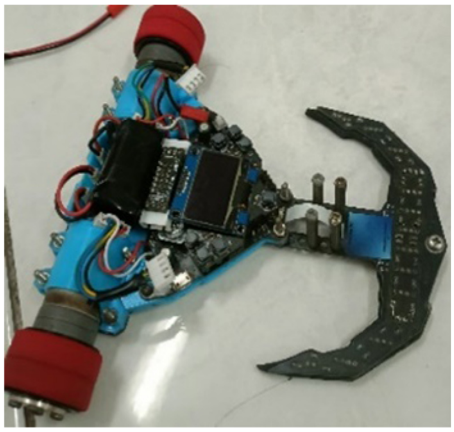
a)

b)


Fig. 3. Testing the line-following robot

The development of the line-following robot using Corel-Draw X_{12}, Chios, and specified hardware components resulted in a versatile and effective educational tool. These robots not only facilitate the gamification of educational content but also provide hands-on learning experiences that align with constructivist principles. By allowing students to engage with complex concepts in a practical and interactive way, the developed system significantly contributes to the educational objectives of the robotics course.

4.2 Research results

In the analysis stage, the validity and effectiveness of educational tools and activities were evaluated by media and gamification expert validators, as well as by lecturers and learners who participated in the study. The following are the results of the validity and effectiveness analysis of the line-following robot.

Validity test analysis results. The subsequent section details the results of the validity analysis conducted by four expert validators in the fields of media and gamification. This analysis was aimed at assessing the appropriateness, effectiveness, and alignment of the gamified educational tools and activities with established educational standards. The insights provided by these experts offer critical evaluations of the media design, content, and implementation strategies used in the study, ensuring that the developed materials are not only pedagogically sound but also highly effective in fostering constructivist skills in students. These evaluations serve as a strong validation of the research methodology and the innovative educational approach undertaken in this study. The data from the validity test analysis are presented in Tables 7 and 8.

Table 7. Media expert analysis results

Validator	Score																									
	1	s	2	s	3	s	4	s	5	s	6	s	7	s	8	s	9	s	10	s	11	s	12	s	13	s
1	4	3	4	3	4	3	5	4	5	4	5	4	5	4	5	4	5	4	5	4	4	3	4	3	5	4
2	4	3	5	4	4	3	5	4	5	4	5	4	4	3	4	3	4	3	4	3	5	4	5	4	5	4
3	5	4	5	4	5	4	4	3	5	4	5	4	5	4	5	4	5	4	5	4	4	3	5	4	4	3
4	5	4	5	4	5	4	4	3	4	3	4	3	5	4	4	3	4	3	5	4	5	4	4	3	4	3
∑S		14		15		14		14		15		15		15		14		14		15		14		14		14
v	0.88		0.94		0.88		0.88		0.94		0.94		0.94		0.88		0.88		0.94		0.88		0.88		0.88	
Average (v)	0.90																									

The validity analysis, based on the responses from the four media expert validators presented in Table 7, showed a high level of validity for the gamification learning activity using a line-following robot. The average validity score was 0.90, which categorizes this educational approach as "Very Valid." This score reflects strong agreement from the experts regarding the suitability and effectiveness of the media and tools used in this study. The high validity score confirms that the design and implementation of the gamification activities were in line with educational standards and suitable for enhancing constructivist skills in students. These findings support the reliability and effectiveness of the media used in the study, strengthening the credibility of the educational strategies developed. After analyzing the media experts, the next step is to analyze the gamification experts, who are tested on four expert validators; the data analysis results are presented in Table 8, as follows:

Table 8. Gamification expert analysis results

Validator	Score																									
	1	s	2	s	3	s	4	s	5	s	6	s	7	s	8	s	9	s	10	s	11	s	12	s	13	s
1	5	4	5	4	5	4	4	3	5	4	5	4	5	4	5	4	4	3	5	4	5	4	5	4	4	3
2	4	3	5	4	4	3	5	4	5	4	4	3	4	3	5	4	4	3	4	3	5	4	4	3	5	4
3	4	3	4	3	5	4	5	4	4	3	5	4	5	4	5	4	5	4	5	4	4	3	5	4	4	3
4	5	4	5	4	5	4	4	3	4	3	4	3	4	3	4	3	5	4	5	4	4	3	4	3	5	4
∑S		14		15		15		14		14		14		14		15		14		15		14		14		14
v	0.88		0.94		0.94		0.88		0.88		0.88		0.88		0.94		0.88		0.94		0.88		0.88		0.88	
Average (v)	0.89																									

The analysis of validity, based on responses from four expert gamification validators, revealed a strong level of validity for the gamified learning activities utilizing line-following robots. The average validity score was 0.89, placing the educational approach in the "Very Valid" category. This score indicates that the experts largely agreed on the suitability and effectiveness of the gamification elements integrated into the study. The high validity rating confirms that the design and application of these gamified activities are well-aligned with educational objectives and are effective in fostering constructivist skills among students. These results validate the robustness and appropriateness of the gamification strategies employed in the research.

Practicality test analysis results. The following section presents the results of the practicality and effectiveness analysis conducted with the teachers and students who participated in the study. This analysis aimed to evaluate the overall usability, effectiveness, and efficacy of the developed educational tools and activities in a real classroom environment. Feedback from lecturers focused on aspects such as ease of use, teaching motivation, and learning time efficiency, while student responses centered on engagement, motivation, and development of critical constructivist skills. The combined insights from both groups provide a comprehensive understanding of the practical impact and educational value of the gamification approach implemented in this study. The results of the practicality analysis of the lecturer responses are presented in Figure 4.

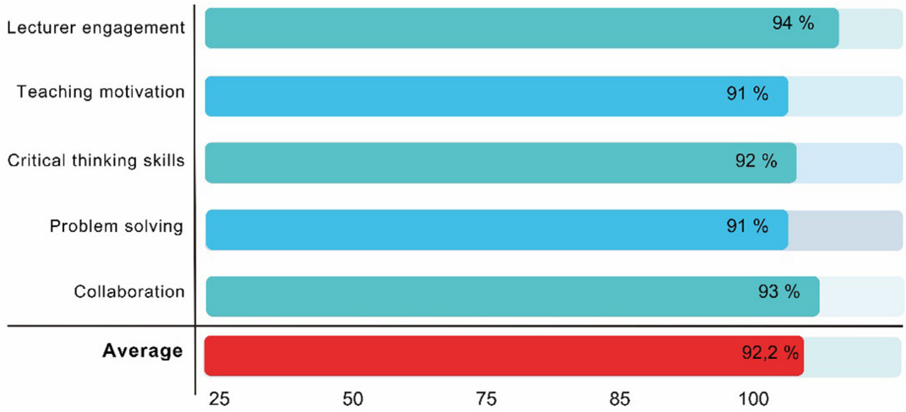


Fig. 4. Practicality analysis results

Figure 4 presents the results of the practical test analysis based on lecturers' responses through questionnaires, which showed very positive results. The gamification expert validity instrument was used to evaluate the effectiveness of integrating gamification elements with the line-following robot in improving key educational outcomes such as student engagement, motivation, critical thinking, problem solving, and collaboration. Analysis of the practical test, based on feedback from lecturers, showed strong support for this gamified learning activity. Lecturer engagement increased significantly, scoring 94%, indicating that the game design elements effectively increased lecturer active participation. Motivation to teach scored 91%, highlighting the positive influence gamification had on lecturers' willingness to engage in learning. Effective material delivery in encouraging critical thinking, as reflected in the score of 92%, indicating the lecturer's ability to encourage students to improve analytical and evaluative skills. Problem-solving skills also saw a significant improvement, with a score of 91%, as lecturers were able to apply logical thinking to overcome learning barriers. Collaboration between lecturers and students was also positively impacted, with a score of 93%, reflecting effective cooperation in achieving learning objectives. Overall, the practicality test showed excellent results, with an average score of 92.2%, underscoring the ease of use, motivational impact, high usability of the robotic platform, and strong support for constructivist pedagogy. These findings further validate the role of the ADDIE model in guiding the development of innovative educational strategies that successfully integrate gamification and robotics.

Effectiveness test analysis results. The next stage of analysis will focus on the effectiveness of student responses in further enhancing constructivist skills, as outlined in the next section. These results emphasize the strong potential of this educational approach to enhance teaching and learning experiences, as shown in the data presented in Figure 5.

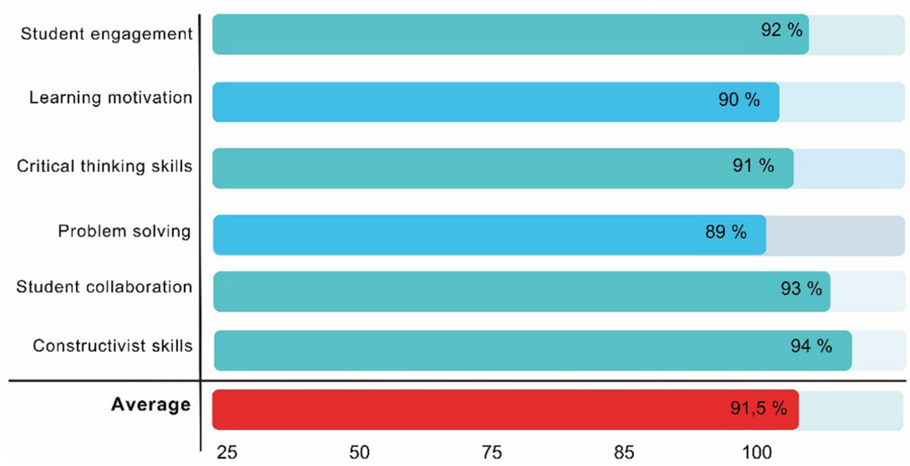


Fig. 5. Effectiveness analysis results

Figure 5 presents the results of the effectiveness test analysis on the improvement of constructivist skills based on student responses through questionnaires that provide strong results, indicating the effectiveness of gamification learning activities using line-following robots. Student engagement scored 92%, indicating a high level of interest and active participation in the learning process. Learning motivation was positively impacted, scoring 90%, showcasing that gamification effectively encouraged students to engage in learning activities. Critical thinking skills were also enhanced, scoring 91%, reflecting the ability of gamified tasks to stimulate students' analytical thinking. Problem-solving abilities showed a significant boost, with a score of 89%, as students were encouraged to apply logical reasoning to overcome challenges presented in the tasks. Collaboration among students was highly rated, scoring 93%, indicating that the gamified activities successfully fostered teamwork and group interaction. The alignment of gamification elements with constructivist learning principles was affirmed, with constructivist skills being rated at 94%, confirming that the activities supported an active, student-centered learning approach. The overall average effectiveness score was 91.5%, indicating the robustness of this educational approach. These results confirm the potential of integrating gamification and robotics to improve student engagement and learning outcomes in enhancing constructivist skills.

4.3 Discussion

This study conducted a comprehensive analysis of the validity and effectiveness of gamified educational tools and activities involving line-following robots. The results are essential for assessing the integration of gamification within an educational context, specifically focusing on enhancing key constructivist skills such as student engagement, motivation, critical thinking, problem-solving, and collaboration.

The findings from the validity test, which was assessed by four expert validators specializing in media and gamification, demonstrated a high level of validity. Media experts rated the approach at 0.90, while gamification experts provided a score of 0.89, placing both in the "Very Valid" category. These results confirm that the design and implementation of the gamified activities aligned well with educational objectives and pedagogical standards. Such strong validation underscores the effectiveness of using gamification elements integrated with line-following robots to support student-centered learning while promoting the development of constructivist skills.

In terms of practicality, the analysis based on lecturer responses was very positive. Key educational outcomes showed a significant increase in lecturer engagement, with a score of 94%, while teaching motivation increased to 91%. The score for critical thinking was 92%, and problem-solving skills scored 91%, further reflecting the success of gamified tasks in encouraging logical reasoning and analytical thinking. In addition, collaboration between lecturers and students scored highly at 93%, underscoring the effectiveness of gamification activities in encouraging teamwork. The overall practicality score of 92.2% indicates that the system is easy to use, motivates lecturers, and is highly usable in real-world educational environments. These findings are in line with the goal of developing tools that support constructivist learning principles, guided by the ADDIE model, to ensure effective pedagogical practices.

The effectiveness analysis, based on student feedback, reinforced the success of the educational approach. Student engagement was rated at 92%, while learning motivation scored 90%, indicating the positive impact of gamification on students' participation and interest in learning. Critical thinking skills were enhanced, as evidenced by the score of 91%, while collaboration among students was rated highly at 93%. These outcomes highlight the ability of gamified activities to promote active, experiential, and student-centered learning. Additionally, problem-solving skills, rated at 89%, demonstrated the effectiveness of the activities in challenging students to apply logical reasoning. Constructivist skills scored the highest at 94%, affirming the alignment of the gamification approach with constructivist learning principles. The overall average effectiveness score of 91.5% underscores the robustness of this educational approach in transforming teaching and learning experiences, particularly in enhancing essential educational skills through gamification and robotics.

These high scores in both practicality and effectiveness indicate significant improvements in key constructivist skills, including critical thinking, creativity, and collaboration. These findings are consistent with existing literature on the benefits of gamification in education, which suggests that gamified approaches can improve educational outcomes [3], [10], [30]. The integration of line-following robots provides an attractive and dynamic platform for implementing such strategies, offering programmable features that allow for a variety of interactive tasks, as supported by previous research [39], [4]. However, the study also identified challenges, such as varying levels of technological proficiency among students and occasional technical issues with the robots. These findings highlight the need for ongoing technical support and training to mitigate such challenges.

The implications of this study suggest that the integration of gamification and robotics offers a practical and effective method for developing 21st-century competencies. This is supported by similar research [40], [14], [41]. Future studies should explore the long-term effects of this approach, its adaptability across different educational settings, and strategies to optimize the balance between challenge and skill levels in gamified tasks. Addressing technical challenges and ensuring equitable access to technology will be crucial in expanding the use of this innovative educational strategy.

5 CONCLUSIONS

This study investigates the integration of gamification and line-following robots to enhance constructivist skills among students, demonstrating significant improvements in student engagement, learning motivation, critical thinking skills, problem solving, and student collaboration. The combination of game design elements with robotic technology creates a dynamic and interactive learning environment that encourages active participation in the learning process. This approach underscores the effectiveness of constructivist learning theory, which emphasizes hands-on, student-centered experiences aligned with the principles of experiential learning. This study shows that gamification not only increases the attractiveness and interest of learning but also improves students' understanding and retention of knowledge. By using line-following robots, lecturers can create scenarios that challenge students to think critically and work collaboratively, thus strengthening key constructivist skills. This study contributes to the expanding body of literature on innovative educational technologies and pedagogies, providing practical insights for lecturers aiming to implement gamified learning experiences, particularly in STEM education. Future research should delve into the long-term impacts of this approach on student learning outcomes, as well as its scalability and adaptability across different educational contexts and age groups. Further exploration of specific game elements and robotic features that most effectively support learning will offer valuable guidance for the design of future educational tools and curricula. The promising results of this study suggest that the intersection of gamification and robotics holds substantial potential for transforming traditional educational practices and enhancing the overall quality of student learning experiences.

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7 AUTHOR CONTRIBUTIONS

Ridho Dedy Arief Budiman: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Software; Visualization; Writing—original draft; Writing—review and editing. **Herman Dwi Surjono:** Validation; Software; Writing—original draft. **Wagiran:** Validation; Software; Writing—original draft. **Maulana:** Methodology; Data curation; Writing—review and editing. **Edi Hidayat:** Data Curation; Investigation; Writing—review and editing. **Syafruddin:** Data curation; Formal analysis; Writing—review and editing.

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