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Development of a STEAM Teaching Module Assisted by Robotics Activities Drive Up a Slope to Enhance Middle School Students' 4C Skills

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Abstract

Integrating mathematics with other fields is necessary for students to tackle real-world problems. Incorporating technology and engineering, such as robotic activities, into science and mathematics teaching offers the potential to improve learning outcomes and enhance students' 4C (Critical Thinking, Creativity, Collaboration, and Communication) skills. This study aims to design and develop a STEAM (Science, Technology, Engineering, Art, and Mathematics) teaching module supported by the robotics activity *Drive Up a Slope* for middle school students and evaluate its feasibility and practicality in enhancing students' 4C skills. The development process of the teaching module follows the ADDIE model (Analyze, Design, Develop, Implement, and Evaluate). The results of this development indicate that the quality of the teaching module is categorized as highly valid, with a validity percentage of 94.64%, and highly practical, with a practicality percentage of 90%. Therefore, it can be concluded that the developed teaching module is both valid and practical.

Keywords: *drive up a slope; teaching modules;4c skills; STEAM*

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INTRODUCTION

The era of the fourth industrial revolution, commonly known as the 21st century, is unfolding globally—a period where digital technology and robotics have become commonplace in all aspects of human life. One of the challenges faced in this era is preparing professional human resources (HR) with cross-disciplinary foundational skills to compete globally. Education in the 21st century refers to an educational framework influenced by the fourth industrial revolution, characterized by the use of digital innovations and computer systems at every phase of the educational process. This system allows education to be delivered continuously and without boundaries (Priantari et al., 2020).

A critical, competitive, creative, and innovative generation must be cultivated to thrive in the industrial revolution 4.0. Education in this era plays a crucial role in integrating the real and virtual worlds to develop students' knowledge and skills for sustainable living. 21st-century learning emphasizes high-order thinking skills (HOTS), involving collaboration, communication, critical thinking, and creativity. HOTS-oriented learning aims to support the development of essential 21st-century skills. However, some individuals feel that this approach does not provide sufficient support for developing these skills and instead adds an additional burden. Despite this, 21st-century skills are essential for students' future careers, yet many students and members of society still lack them. This aligns with Trilling & Fadel (2009), who state that high school and university graduates often lack basic and applied skills.

One educational approach that addresses the needs of 21st-century learning is STEAM (Science, Technology, Engineering, Art, and Mathematics) education. STEAM is a teaching method gaining attention among educators for its integration of knowledge and skills across multiple disciplines to solve challenges and foster structured thinking. Henriksen (2017) emphasizes that STEAM learning can stimulate critical thinking and equip students to face the challenges of globalization.

The need for students to develop critical thinking, problem-solving, creativity, innovation, collaboration, and communication aligns with STEAM education. The Partnership for 21st Century Skills identifies these competencies, known as the 4Cs (Creativity, Critical Thinking, Communication, and Collaboration), as essential in the 21st century. These skills are considered crucial for Indonesian students, as highlighted by Septikasari & Frasandy (2018), who stress the importance of collective efforts in preparing young generations for the future. According to Safitri (2020), the 4Cs are soft skills that offer more benefits than hard skills.

One suitable activity for STEAM learning is robotics Jaipal-Jamani (2023). The primary goal of robotics in education is to allow students to control real-world models in a virtual environment (Alimisis, 2012). Robotics enables students to build physical objects and interact with them directly, enhancing critical thinking, motivation, and computational fluency (Kucuk & Sisman, 2020). Robotics activities are particularly effective in fostering 21st-century skills and have become increasingly integrated into STEAM education in recent years. Toh et al. (2016) state that robotics-based learning provides students with opportunities to develop academic and interactive learning skills.

The success of a learning process depends on the teaching strategies, methodologies, and materials used, including teaching modules. Teaching modules are curriculum-based tools designed to achieve specific competency standards. In 21st-century mathematics education, teaching modules play a critical role in helping educators design effective lessons (Nesri & Kristanto, 2020). Pepin et al. (2017) emphasize that well-designed modules focusing on 21st-century skills can significantly enhance student learning. Integrating technology into teaching modules offers the potential to improve learning outcomes, as technology becomes increasingly accessible to students.

Researchers are currently developing self-assembly robotics kits designed to stimulate STEAM-related concepts and thinking methods. These kits include various components such as motors, sensors, wheels, gears, and everything needed to build a robot. One of the most comprehensive kits available on the market for building robots is the *Lego MINDSTORMS EV3*. This kit not only provides an engaging and enjoyable experience but also supports educational processes (Cruz-Martín et al., 2012). It is both appealing and practical, as it is based on Lego's play system, as shown in Figure 1. The programming language used is visual, requiring only an understanding of the symbols and icons.

One of the *Lego MINDSTORMS EV3* robotics kits is *Drive Up a Slope*, illustrated in Figure 2. This robot is designed to climb steep slopes. It helps students develop critical thinking and problem-solving skills by figuring out how to make the robot successfully ascend a steep incline. Through the *Drive Up a Slope* activity, students are expected to analyze the STEAM components involved in the task.

Figure 1: *Lego MINDSTORMS EV3* Kit

Figure 2: Example of *Drive Up a Slope* Robot from *Lego MINDSTORMS EV3*

Discussions on the use of robotics in STEAM education at the secondary level, particularly in developed countries, are relatively abundant. However, few resources comprehensively explain how robotics can be used as a teaching tool or simulator in learning activities. This lack of references limits educators' understanding of how robotics can be applied in STEAM education, especially in secondary education. Therefore, this study aims to design and develop a teaching module that integrates robotics activities into STEAM learning for middle school students.

RESEARCH METHODOLOGY

This research was conducted at a private junior high school (SMP) in Yogyakarta on May 24, 2024, and May 31, 2024, involving 12 seventh-grade students and two product validators as the research subjects. This development research employed the Research and Development (R&D) method. According to Sugiyono (2022), R&D is a research method used to create products and test their effectiveness. The development model used in this study follows the ADDIE model (Analysis, Design, Develop, Implement, Evaluate).

The *analyze* phase aims to determine the extent of mathematics learning in seventh-grade junior high school (SMP). It also involves analyzing the needs to ensure that the developed product aligns with the required competencies and meets the students' needs as the target users of the teaching module. This process includes identifying problems within the school, examining the alignment between the SMP curriculum and STEAM learning—particularly through the application of robotics to be explored—and analyzing the characteristics of the students to ensure the teaching module is tailored to their needs and abilities.

In the *design* phase, the researcher develops the teaching module based on the results from the *analyze* phase. This process includes planning the development of the

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module, which involves designing its components and organizing the module content. Additionally, the researcher prepares assessment instruments to evaluate the product, including expert validation and a questionnaire to gather student feedback.

In the *development* phase, the module undergoes expert validation. Before implementation, the module must be deemed appropriate and valid. The validation data from experts are analyzed to determine the module's validity and to identify necessary revisions based on their input and suggestions. The *implementation* phase involves a limited trial with seventh-grade junior high school students to assess the readability of the STEAM teaching module. After the trial, students are asked to complete a questionnaire to collect data on the module’s practicality and to provide comments and suggestions.

The *evaluation* phase is the final stage of development, where the learning activities using the STEAM teaching module, supported by robotics activities, are assessed. This stage is crucial for measuring the module’s effectiveness and improving its quality. The objective of this phase is to identify the strengths and weaknesses of the teaching module after its implementation.

In this study, two types of data were used: qualitative and quantitative. Qualitative data were obtained through interviews with teachers, as well as feedback and suggestions from validators and students. Meanwhile, quantitative data were collected from the validators' assessments to evaluate the validity of the teaching module and from student questionnaire responses to assess the module's practicality. Data collection techniques included interviews, literature review, and questionnaire distribution.

In the development process of the STEAM teaching module supported by robotics activities, the module's validity was tested, and student responses were analyzed to determine its practicality. The assessment of the module’s validity and practicality was conducted using a Likert scale. The Likert scale used for evaluation ranges from 1 to 5. The criteria for evaluation are presented in Table 1.

Table 1. Expert Validation Scores for Content and Media, and Practicality Assessment Scores for the Teaching Module (Sugiyono, 2022)

Score	Description
1	Very Poor
2	Poor
3	Fair
4	Good
5	Very Good

The validity and practicality percentages were calculated using the following formula (adapted from Maya (2022)):

$$\text{Feasibility Percentage } (x) = \frac{\text{Total Score}}{\text{Maximum Score}} \times 100\%$$

The resulting percentages were categorized based on validity and practicality criteria based on Tables 1 and 2.

Table 2. Criteria for Content Validity and Criteria for Media Validity (Nesri & Kristanto, 2020)

No	Validity Percentage	Validity Level
1	$85\% < x \leq 100\%$	Very valid
2	$70\% < x \leq 85\%$	Valid
3	$50\% < x \leq 70\%$	Less valid
4	$x \leq 50\%$	Not valid

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Table 3. Criteria for Product Practicality (Nesri & Kristanto, 2020)

No	Practicality Percentage	Practicality Level
1	$80\% < x \leq 100\%$	Very practical
2	$60\% < x \leq 80\%$	Practical
3	$40\% < x \leq 60\%$	Less practical
4	$20\% < x \leq 40\%$	Not practical
5	$0 < x \leq 20\%$	Very not practical

RESULTS AND DISCUSSION

During the *analysis* stage, the researcher conducted interviews with a mathematics teacher. Based on the interview results, it was revealed that SMP Stella Duce 1 Yogyakarta is already using the independent curriculum (Kurikulum Merdeka). The teacher mentioned that one of the challenges frequently encountered during mathematics lessons is maintaining students' concentration, as seventh-grade students are transitioning from elementary school and still exhibit childish behaviors.

The teacher has optimized the learning process according to the independent curriculum, which requires students to utilize available technology and develop 21st-century skills such as collaboration, communication, critical thinking, and creativity. Students are also encouraged to actively participate in learning. However, the teacher noted that students often struggle to remain focused; they frequently design or create things and experiment outside the learning topic, which can disrupt the lesson. This issue, though disruptive, is viewed positively as it indicates students' creative ideas, which could be further developed if appropriately integrated into mathematics learning. The teacher expressed a desire to facilitate student experimentation in mathematics but is hindered by limited resources.

In the curriculum analysis stage, learning objectives and outcomes were identified. Since SMP Stella Duce 1 Yogyakarta follows the independent curriculum, the learning module to be designed will align with it. The researcher identified learning outcomes and formulated specific learning objectives by accessing the official website of the Ministry of Education and Culture (Kemendikbud) and aligning them with the STEAM activities integrated into the developed module.

The identified learning outcomes are as follows: (1) **Science**: Students understand the concept of motion, (2) **Technology**: Students can apply procedural programming concepts in a specific programming language, (3) **Engineering**: Students can design applied technological solutions by exploring materials, techniques, and procedures, (4) **Arts**: Students can recognize the relationship between art and other fields of science, (5) **Mathematics**: Students can read, write, and identify ratios.

The formulated learning objectives include: (1) stating the ratio of two quantities, (2) writing and determining ratios, (3) explaining the concept of motion in daily life, (4) designing the *Drive Up a Slope* project accurately through assembly activities, (5) programming the project following the coding procedures for *Drive Up a Slope*, (6) combining various techniques, materials, and tools to produce an artistic creation, (7) identifying real-life applications of *Drive Up a Slope*, (8) testing and evaluating the *Drive Up a Slope* design, and (9) presenting the final design of *Drive Up a Slope* effectively.

The teacher also highlighted the diverse characteristics of students, noting that their abilities vary significantly. Students are generally uninterested in monotonous lessons with repetitive models or methods. They tend to prefer learning activities that utilize new and different models or methods, which increase their engagement and concentration. Additionally, students enjoy experimenting and designing projects, even if they fall outside the lesson context. Group-based learning is also more appealing to them. Based on these observations, it is necessary to develop a learning module that facilitates students in mastering 21st-century skills and encourages them to experiment in mathematics.

Therefore, the researcher developed a STEAM learning module supported by robotics activities to enhance students' 4C (Critical Thinking, Creativity, Collaboration, and Communication) skills.

During the design stage, several aspects of the learning module were developed, including the module components and structure. The components of the STEAM learning module with robotics activities are divided into three sections: general information, core components, and the final section. The general information section is illustrated in Figure 3.

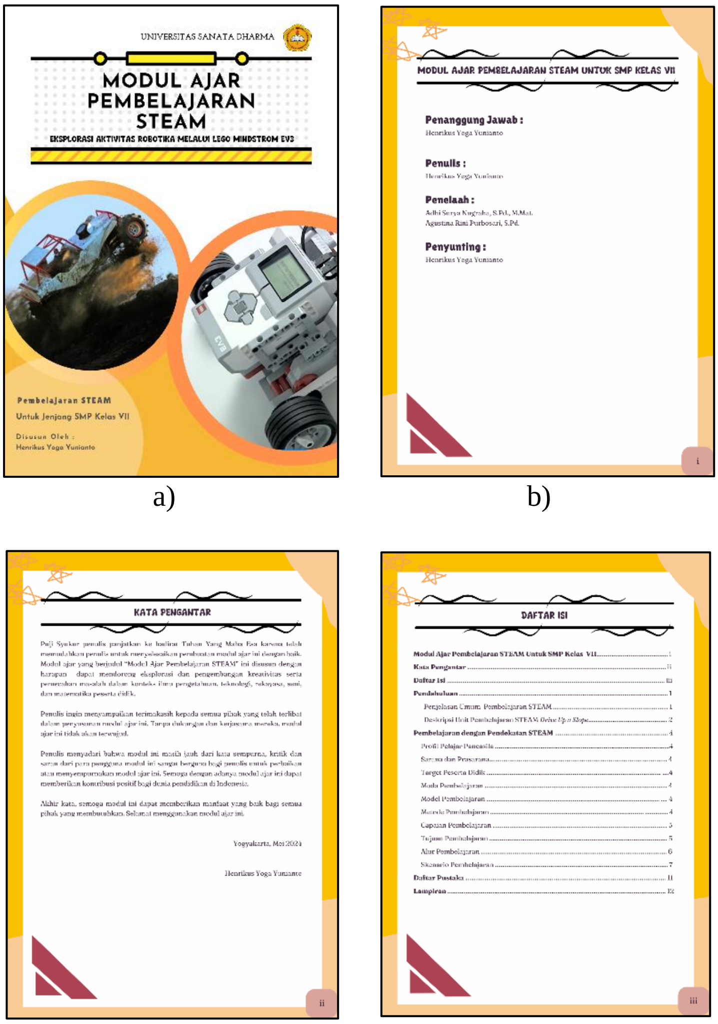


Figure 3. General Information Sections of the Learning Module: a) Cover, b) Module Identity Sheet, c) Preface, and d) Table of Contents.

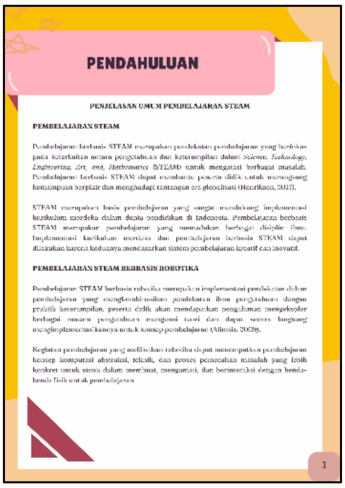
Figure 3 depicts the general information components of the module: a) Cover: The researcher selected a design featuring a robot motif and contextual imagery of the robot used in the project. The cover also includes information about the module, such as the title, topic, target users, and the author's name, making it easier for teachers to identify the module.
b) Module Identity Sheet: This section provides information about the individuals involved in the module's development, including the person in charge, authors, reviewers, and editors.

c) Preface: It contains a summary of the module's content, the author's expectations for students after completing the module, acknowledgments to those involved in its development, and a request for feedback and suggestions for future improvements. d) Table of Contents: This section provides a summary or general overview of the module's contents, helping readers easily navigate through the topics.

The core components include introduction, general information, and learning outcome, as illustrated in Figure 4. Introduction divided into three sections: General Explanation of STEAM Learning, Explanation of *Lego MINDSTORMS EV3* and *Drive Up a Slope*, and STEAM Aspects in Building *Drive Up a Slope.* General Explanation of STEAM Learning describes STEAM learning integrated with the Merdeka Curriculum in Indonesian education. Additionally, it provides an example of implementation through robotics-based STEAM learning. Explanation of *Lego MINDSTORMS EV3* and *Drive Up a Slope* describes the product used in the STEAM learning implementation—*Drive Up a Slope*—and the robotics equipment, *Lego MINDSTORMS EV3*. STEAM Aspects section offers an overview of the STEAM aspects involved in constructing *Drive Up a Slope* and its role in the learning process: (1) Science: Movement of Drive Up a Slope, (2) Technology: Assembling and inputting the driving program using blocks on Drive Up a Slope, (3) Engineering: Designing and assembling Drive Up a Slope, (4) Art: Identifying the connection between Drive Up a Slope and art, (5) Mathematics: Identifying ratios.

The second core component, general information, includes the General Module Information, Learning Outcomes and Objective, as well as Learning Flow and Learning Scenario.

- *General Module Information*: (1) Profile of Pancasila Students (faith in God, critical reasoning, creativity, and teamwork), (2) Facilities and Infrastructure, (3) Target Learners, (4) Mode of Learning: Face-to-face, (5) Learning Model: Project-Based Learning (PBL), using discussion and presentation methods.
- *Learning Outcomes (CP):* (1) Science: Students understand motion, (2) Technology: Students can apply procedural programming concepts in a programming language, (3) Engineering: Students can create engineering designs from exploring materials, techniques, and procedures, (4) Art: Students can see the relationship between art and other scientific fields, (5) Mathematics: Students can read, write, and identify ratios.
- *Learning Objectives (TP):* (1) Express the ratio of two quantities, (2) Write and determine ratios or proportions, (3) Explain the concept of motion in daily life, (4) Design the Drive Up a Slope model accurately through assembly activities, (5) Input a program correctly based on the Drive Up a Slope Coding Tips procedure, (6) Combine various techniques, materials, and tools to produce an artistic creation, (7) Identify the use of Drive Up a Slope in daily life, (8) Test and evaluate the Drive Up a Slope design, (9) Communicate the final design of Drive Up a Slope effectively through presentations.
- *Learning Flow and Learning Scenario* that is designed based on the characteristics of the learners and the theme of the teaching module. The researcher adopts the 5E learning cycle model, adapted from the Drive Up a Slope Lesson Plan on the official Lego Education website. This STEAM-based learning unit is intended for 7th-grade junior high school students and focuses solely on integrating mathematics learning with STEAM.



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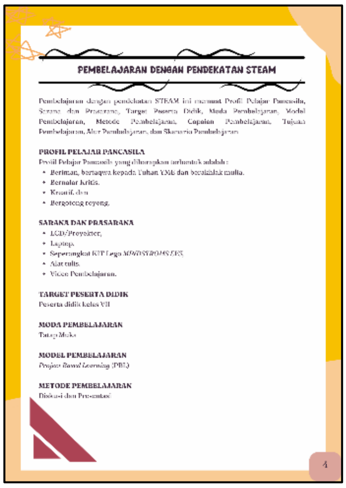

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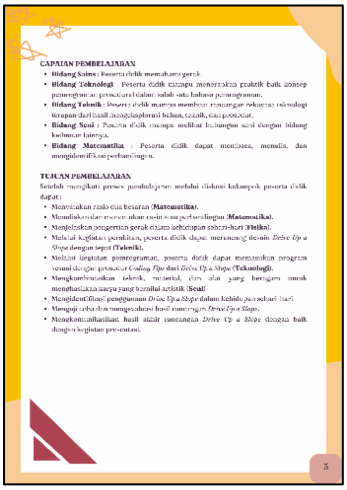

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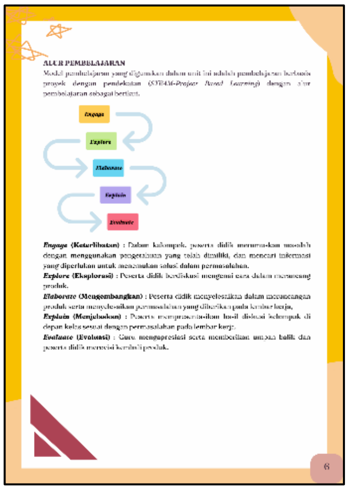
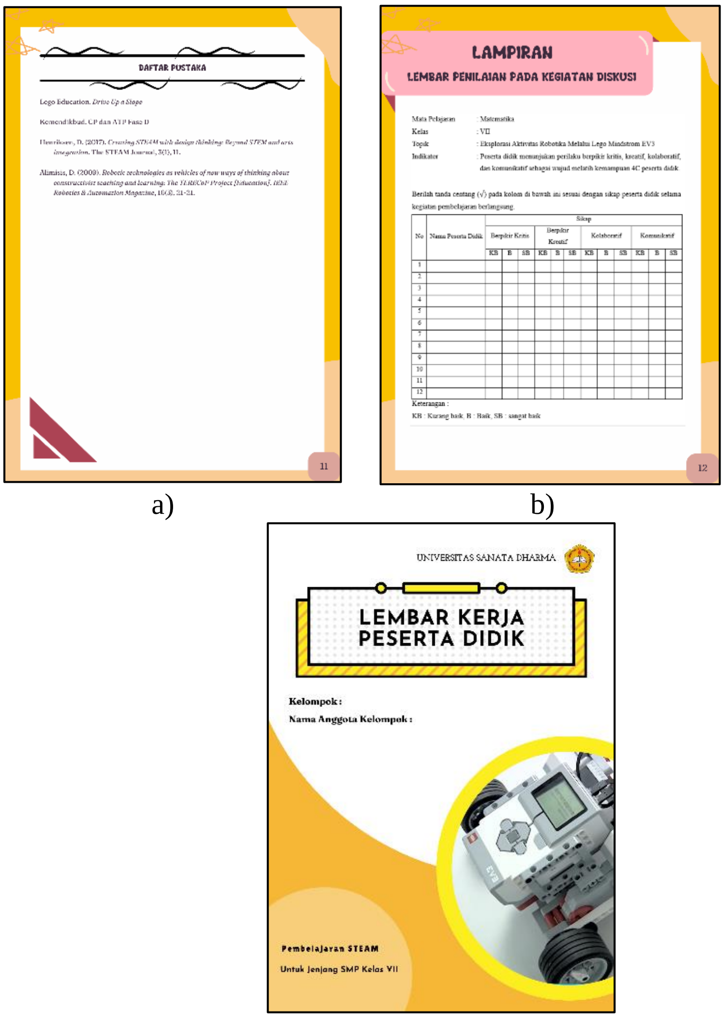


d)

Figure 4. Core Components of the Teaching Module

The final section, as the third core component is the appendix. This section includes References, Assessment Attachments, and Student Worksheets (LKPD). The appendix section is shown in Figure 5.

After determining the creation and design of the product, the researcher proceeded to development stage. Development stage involves printing the designed teaching module, which is then ready for classroom trials. Before testing in the classroom, the module was first validated by experts and revised based on their feedback. The teaching module consists of 42 pages and was printed on A4 paper (29.7 × 21 cm). The validation process yielded several comments and suggestions, including: allocating specific time for each activity, using contextual or real-life videos for problem scenarios, and clarifying the instructions for each activity. All feedback was incorporated into the revisions before the trial phase.



a) b)

c)

Figure 5. Appendix Section of the Teaching Module

At the *implementation* stage, the module was tested with a limited trial group of 12 seventh-grade students. The learning sessions were allocated 120 minutes (3 teaching periods) and conducted over two sessions, on Friday, May 24, 2024, and Friday, May 31, 2024. During the implementation of the STEAM teaching module with robotics activities, students demonstrated their mastery of 21st-century skills (4C). The STEAM module with robotics activities encouraged students to think critically in designing, solving problems, and analyzing the results of robotics tasks. Students demonstrated creativity by designing and building robots to meet specific objectives, developing unique and innovative solutions. Robotics activities required students to collaborate in groups, communicate, and share ideas to achieve common goals. Within their groups, students presented their ideas, explained concepts, and engaged in discussions with peers and teachers.

After the limited trial, at evaluation stage, the researcher distributed a questionnaire to gather student feedback on the learning experience with the STEAM teaching module integrated with robotics. The results revealed that students found the learning experience exciting and enjoyable, particularly because the module facilitated hands-on experimentation in mathematics, such as building robots and connecting the activities to mathematical concepts. Students expressed a keen interest in the learning process, especially since robotics was a new experience for them. Their enthusiasm was evident during the robot assembly, programming, and testing phases.

The researcher also provided an evaluation of the session, highlighting some points. The allocated time was insufficient to complete all the activities due to the extensive content, leading to some skipped activities. The sequence of activities would be more effective if implemented in a robotics extracurricular program, as the trial participants were students with prior experience in robotics and coding, which facilitated smoother learning.

At the *evaluation* stage, the researcher also assessed the learning outcomes based on the assessment rubric, covering both discussion and project aspects to ensure the module's clarity and effectiveness. The assessment results provided by the teacher are shown in Figure 6 and 7.

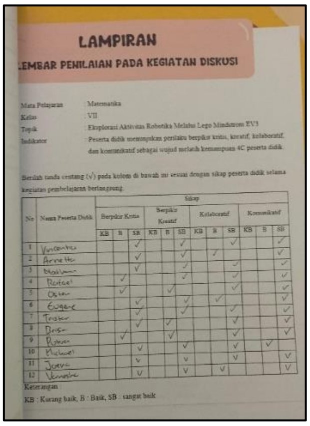
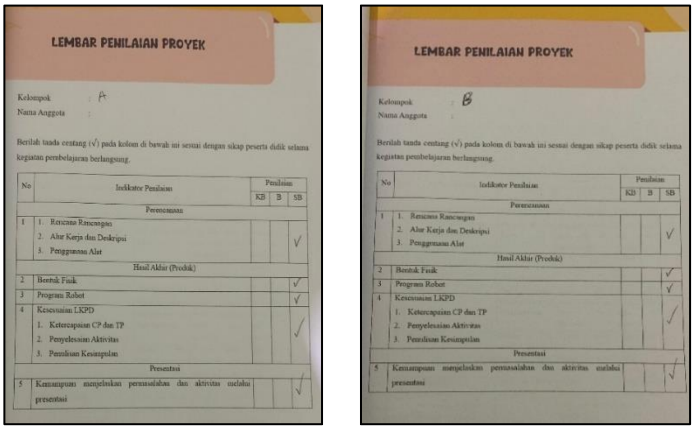


Figure 6. Assessment of Discussion Activities



a) b)

Figure 7. Project Assessment for Group A and Group B

Validity of the Teaching Module

The validity of the teaching module was evaluated with the help of expert validators to assess its feasibility before testing student responses. This validation involved two experts: a university lecturer and a middle school mathematics teacher. The results from both validators are shown in Tables 4 and 5.

Table 4. Validation Results by Subject and Media Expert (Validator 1)

No	Assessment Aspect	Percentage	Category
1	Content Feasibility	93,85%	Very Valid
2	Language Feasibility	96,67%	Very Valid
3	Presentation	91,1%	Very Valid
4	Independent Learning	90%	Very Valid
5	STEAM Approach	80%	Good
6	Module Size	100%	Very Valid
7	Module Cover Design	100%	Very Valid
8	Module Content Design	100%	Very Valid
	Average	**93.95%**	**Very Valid**

The lecturer's evaluation yielded a score of 93.85% for content feasibility, 96.67% for language feasibility, 91.1% for presentation, 90% for independent learning, 80% for the STEAM approach, 100% for module size, 100% for the cover design, and 100% for the content design. The average score across all eight aspects was 93.95%, placing the module in the "Very Valid" category.

Table 5. Validation Results by Subject and Media Expert (Validator 2)

No	Assessment Aspect	Percentage	Category
1	Content Feasibility	96,92%	Very Valid
2	Language Feasibility	86,67%	Very Valid
3	Presentation	91,1%	Very Valid
4	Independent Learning	90%	Very Valid
5	STEAM Approach	100%	Very Valid
6	Module Size	100%	Very Valid
7	Module Cover Design	100%	Very Valid
8	Module Content Design	98%	Very Valid
	Average	**93.95%**	**Very Valid**

The mathematics teacher's evaluation provided scores of 96.92% for content feasibility, 86.67% for language feasibility, 91.1% for presentation, 90% for independent learning, 100% for the STEAM approach, 100% for module size, 100% for cover design, and 98% for content design. The overall average was 95.33%, categorizing the module as "Very Valid." The overall average validity score from both validators is shown in Table 6.

Table 6. Final Validation Percentage of Teaching Module

No	Validator	Percentage	Category
1	Mathematics Lecturer	93,95%	Very valid
2	Mathematics Teacher	95,33%	Very valid
	Average	**94,64%**	**Very valid**

With an average validity score of 94.64%, the STEAM-based teaching module is categorized as "Very Valid." This indicates that the module aligns well with the STEAM concept and is comprehensible for users. This result supports Ayriza's (2008) statement that module validation aims to ensure the module's compatibility with the concept and its readability by users.

Practicality of the Teaching Module

The practicality of the teaching module was assessed through a student questionnaire. The aspects evaluated included module design, clarity of instructions, incorporation of 4C skills, and the relevance of the problems presented. The results are presented in Table 7.

Table 7. Practicality Results of Teaching Module

No	Aspect	Persentase	Kategori
1	Module Design	91,67%	Very Practical
2	Clarity of Instructions	85,83%	Very Practical
3	4C Skills Integration	94.17%	Very Practical
4	Relevance of Problems to Topic	88,33%	Very Practical
	Average	**90%**	**Very Practical**

The students provided scores of 91.67% for module design, 85.83% for clarity of instructions, 94.17% for 4C skills integration, and 88.33% for the relevance of problems to the topic. The overall average score was 90%, placing the module in the "Very Practical" category.

The STEAM-based teaching module is both valid and practical for use in educational settings. This finding aligns with Fauzan's (2002) assertion that a teaching material's practicality is determined by its appeal and usability. The developed module is engaging and effectively supports students in learning mathematics through robotics-based activities.

CONCLUSION AND SUGGESTIONS

This research and development produced a STEAM-based teaching module incorporating robotics activities, focusing on mathematics, specifically the topic of ratios. The STEAM-based teaching module was developed using the ADDIE model (Analyze, Design, Development, Implementation, Evaluation). The quality and readability of the developed teaching module meet high standards and enhance students' 4C skills (Critical Thinking, Creativity, Collaboration, and Communication). This is supported by the evaluation results from a mathematics lecturer and a mathematics teacher, with scores of 93.95% (very valid) and 95.33% (very valid), respectively. The average validity score from both validators is 94.64%, indicating a "very valid" level of validity. Additionally, based on student responses regarding the practicality of the teaching module, an average score of 90% was obtained, placing the module in the "very practical" category.

The STEAM module with robotics activities encouraged students to think critically in designing, solving problems, and analyzing the results of robotics tasks. Students demonstrated creativity by designing and building robots to meet specific objectives, developing unique and innovative solutions. Robotics activities required students to collaborate in groups, communicate, and share ideas to achieve common goals. Within their groups, students presented their ideas, explained concepts, and engaged in discussions with peers and teachers.

It can be concluded that the teaching module is highly feasible, practical, and enhances middle school students' 4C skills. However, its effectiveness in improving students' 4C skills needs to be measured over a longer period through testing. The researcher also suggests that future studies integrate the Pythagorean Theorem into the STEAM framework for mathematics, following the guidance of the *Drive Up a Slope* manual. Moreover, product development should incorporate all aspects of STEAM, enabling collaboration with experts from related fields.

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