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DEVELOPMENT OF AN AUTOMATED CAR–BASED STEM LEARNING MEDIA ON MOTION TOPICS TO FOSTER HIGHER-ORDER THINKING SKILLS OF JUNIOR HIGH SCHOOL STUDENTS

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ABSTRACT

This study aims to develop a STEM-based learning medium in the form of an automated car for teaching motion and force concepts as an effort to enhance the Higher-Order Thinking Skills (HOTS) of junior high school students. The background of this research is based on the low level of students' HOTS in physics learning, limited laboratory facilities, and the continued dominance of conventional teaching methods that provide insufficient meaningful learning experiences. The research employed a Research and Development (R&D) method using the 4D development model, which consists of the Define, Design, Develop, and Disseminate stages. The product developed was a STEM-based automated car learning media package, complemented by a user guide to support instructional activities. Validation was conducted by media experts and subject-matter experts to assess the feasibility of the product in terms of content accuracy, design quality, and functional performance. Furthermore, practicality testing was carried out through limited trials involving science teachers and junior high school students. The results indicate that the STEM-based automated car learning media achieved a valid level of feasibility and a very high level of practicality. These findings suggest that the developed media is easy to use, engaging, and well aligned with students' characteristics. Therefore, the STEM-based automated car learning media is suitable for use as an alternative instructional tool to support students' understanding of motion and force concepts while fostering higher-order thinking skills.

Keywords: STEM Learning Media, Automated Car, Motion and Force, Higher-Order Thinking Skills, Junior High School

A. Introduction

Science learning, particularly physics, plays a crucial role in equipping students with scientific reasoning abilities and higher-order thinking skills (HOTS) (Rahwati & Putri, 2024). The current educational curriculum emphasizes learning processes that go beyond mere conceptual understanding, focusing instead on students' abilities to analyze, evaluate, and solve problems through meaningful learning experiences. One instructional approach considered effective in addressing these demands is the

Science, Technology, Engineering, and Mathematics (STEM) approach (Arafat et al., 2024; Yuliati & Saputra, 2019), as it integrates multiple disciplines to systematically solve real-world problems.

The topics of motion and force constitute fundamental concepts in physics that require students to develop strong conceptual understanding and analytical skills. Ideally, instruction on these topics should be implemented through experimental activities, the use of concrete learning media (Mardiana et al., 2022), and the application of concepts within real-life contexts. Through contextual and problem-based learning, students are expected to develop higher-order thinking skills (HOTS) optimally. However, based on the learning conditions examined in this study, physics instruction at the junior high school level remains predominantly characterized by conventional, teacher-centered approaches (Djalal, 2017). Learning activities are largely conducted through lectures and routine problem-solving exercises, resulting in limited active student engagement.

The gap between ideal learning expectations and actual classroom practices is further reinforced by limitations in instructional media and supporting facilities. Not all schools are equipped with adequate laboratory infrastructure, resulting in physics practical activities on motion and force topics being inadequately implemented (Widiarini et al., 2025). Consequently, students often experience difficulties in understanding abstract concepts and tend to rely on memorizing formulas without comprehending their physical meanings. This condition contributes to low levels of students' higher-order thinking skills, particularly in analyzing problems and applying physics concepts to real-world situations.

Various relevant studies indicate that the implementation of STEM-based learning supported by innovative instructional media can enhance student engagement, conceptual understanding, and higher-order thinking skills. Learning media that integrate elements of technology and engineering enable students to learn through hands-on activities and problem-solving experiences (Handayani et al., 2023; Nisa et al., 2022). Therefore, the development of STEM-based learning media in the form of an automated car for teaching motion and force concepts represents a relevant alternative solution. This media is expected to bridge the gap between ideal learning demands and actual classroom practices while supporting the more optimal development of students' higher-order thinking skills (Brender et al., 2021).

B. Research Method

This study was conducted at SMP Negeri 1 Pekanbaru. The research subjects included expert validators, consisting of subject-matter experts and media experts, science teachers, and junior high school students who participated in the limited trial of the learning media. The research data were obtained through expert validation and practicality testing involving teachers and students as media users. All collected data were analyzed using descriptive quantitative methods to provide an objective overview of the quality of the developed product.

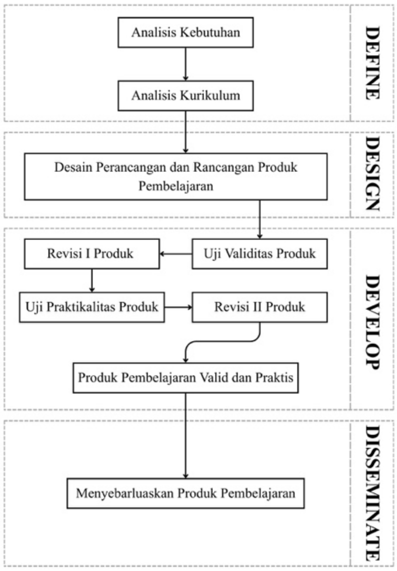


Figure 1. Research and Development Scheme Using the 4D Model

The development process followed the 4D development framework, as illustrated in Figure 1. The Define stage aimed to analyze learning needs, student characteristics, and problems encountered in physics learning. The Design stage involved designing the STEM-based automated car learning media along with the development of a user guide. The Develop stage included product development, validation by subject-matter experts and media experts, and revisions based on the suggestions provided. Subsequently, practicality testing was conducted involving teachers and students. The Disseminate stage was implemented on a limited scale through the distribution and use of the learning media within the research school environment.

The validity assessment categories for the developed STEM-based learning media were determined using a Likert scale, as presented in Table 3.

Table 3. Likert Scale Categories for Validity Assessment (References: Annisa & Darassuyamsu, 2023)

Category	Score
Strongly Agree	4
Agree	3
Disagree	2
Strongly Disagree	1

The level of validity was determined based on the validity categories as presented in Table 4.

Table 4. Validity Categories References: (Adaptation from Widoyoko, 2015:69)

No.	Score Range	Description
1.	$3 \leq \bar{x} \leq 4$	Valid
2.	$\bar{x} < 3$	Not Valid

The results of the validity analysis were used as the basis for revising and refining the learning media before it was implemented in the user trial stage.

Next, the analysis of practicality data was conducted based on the responses from teachers and students after using the learning media during the instructional activities, as presented in Table 9.

Table 9. Practicality Categories (References: Adaptation from Annisa & Darassuyamsu, 2023)

Percentage (%)	Score	Description
$P \leq 76$	4	Very Practical
$51 \leq P \leq 75$	3	Practical
$26 \leq P \leq 50$	2	Not Practical
$P \leq 25$	1	Very Not Practical

Based on the analysis of validity and practicality data, the feasibility of the STEM-based learning media in the form of an automatic car can be determined. The learning media is considered suitable for use if it meets the minimum criteria of being both valid and practical. This analysis serves as the basis for drawing conclusions regarding the product's feasibility and provides recommendations for its application in teaching physics, specifically on the topics of motion and force.

C. Results and Discussion

This study produced a STEM-based learning media in the form of an automatic car, accompanied by a user guide, designed for teaching motion and force to junior high school students.

Define

The analysis was conducted by gathering information through a literature review related to the design and development of research products addressing learning problems in motion and higher-order thinking skills (HOTS), as well as by collecting direct information from schools. Some of the information obtained is as follows:

a. The main challenge in the Merdeka Curriculum for the topic of motion and forces is students' difficulty in connecting concepts with real-life applications. Teachers often need to reteach mathematical calculations because students struggle to apply formulas to problems (Maulidina & Khusaini, 2023).
b. The implementation of innovative learning models, such as Project-Based Learning (PjBL) integrated with the STEM approach, has been shown to significantly enhance students' higher-order thinking skills in the areas of analyzing, evaluating, and creating (Fitriyani et al., 2020).

At this needs analysis stage, information was also collected directly from the school through a student questionnaire at SMP Negeri 1 Pekanbaru and the administration of an initial HOTS test. Some of the key findings from the school data are as follows:

a. Teachers tend to design questions that target Lower Order Thinking Skills (LOTS), making it difficult for students to develop higher-order thinking skills.
b. The results of the students' initial HOTS test indicate that their higher-order thinking skills are still in the low category, with only 37.8% of students able to answer the questions correctly.
c. Questionnaire data show that 43.8% of students have never used technology- or robotics-based media in science learning.
d. As many as 72.3% of students stated that they highly need robotics media assembly activities in the classroom, as they are considered challenging and help in understanding motion concepts concretely.

The development of learning media in the form of an automatic car must, of course, be supported and aligned with the curriculum currently used by schools. As of 2025, schools have generally adopted the Merdeka Curriculum with a Deep Learning approach. The development of this STEM-based learning media is strategically aligned with the Merdeka Curriculum, which emphasizes a Deep

Learning approach. This pedagogical shift moves away from teacher-centered methods toward a process that is mindful, meaningful, and joyful, positioning educators as facilitators of active inquiry (Triyana & Husamah , 2025). Under Ministry of Education Regulation No. 56/M/2022, the curriculum grants educators the flexibility to design high-quality, student-centered experiences tailored to local needs.

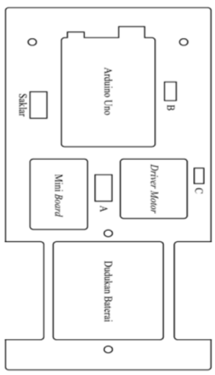
Integrating the automatic car project into co-curricular activities directly supports the development of the Pancasila Student Profile, fostering critical reasoning and noble character through hands-on interaction. Furthermore, in accordance with BSKAP Decree No. 008/H/KR/2022, the use of robotic media facilitates a three-stage learning cycle: conceptual understanding, practical application, and real-world outcomes. Consequently, this STEM media serves as a vital tool for implementing deep learning and scientific investigation within the modern curriculum framework.

Based on this analysis, the researcher concludes that science learning, particularly the topic of motion in 7th-grade junior high school, requires learning media capable of supporting deep learning activities in both intrakuricular and co-curricular sessions. Therefore, the researcher developed the STEM Automatic Car Learning Media as a solution to foster meaningful and enjoyable higher-order thinking skills in students.

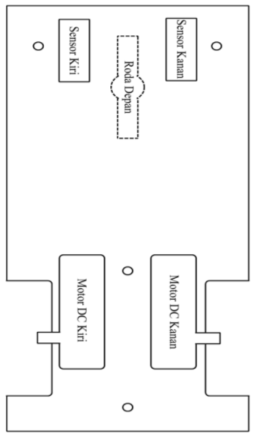
Design

The researcher designed STEM Automatic Car learning media along with its guidebook. Naturally, the process required continuous testing and trials to achieve satisfactory results. The design of the automatic car utilizes a plywood board and several key components, including an Arduino, motor driver, mini board, battery holder, TCRT5000 sensor, and DC motor. The initial design of the automatic car is illustrated in Figures 2 and Figure 3.

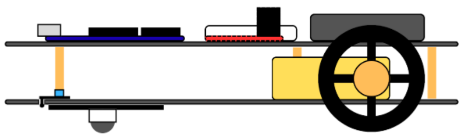
Figures 2. Design of the Automatic Car (a) the top board, (b) the bottom board, and (c) side view.



(a)

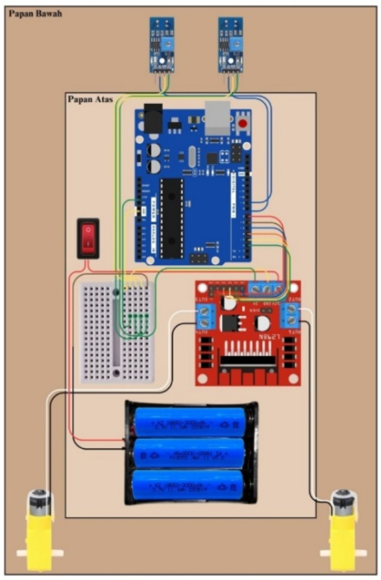


(b)



(c)

Figure 3. Design of the Automatic Car Wiring Diagram



Develop

This stage represents the core of the product development process, where the product namely the STEM Automatic Car Learning Media and its guidebook has been fully designed. The product is then subjected to validation and practicality testing by teachers and students through a limited trial.

1. Description of the STEM Automatic Car Learning Media

The learning media developed in this study consists of the STEM Automatic Car learning media along with its guidebook, intended for use in teaching the motion topic in 7th-grade junior high school. The activities conducted in this study included validity testing by subject matter experts and practicality testing by science teachers and students through a limited trial.

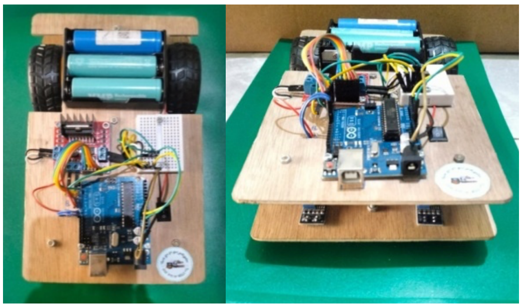
The validation stage was carried out to assess the feasibility of the STEM Automatic Car learning media and its guidebook. Experts ensured that the media was not only visually appealing but also accurate in terms of content and functionality. In the validation process, several assessment aspects were considered. For the STEM Automatic Car learning media, the aspects included device functionality, educational elements, ease of use, and aesthetics and construction. Meanwhile, for the guidebook, the assessment aspects consisted of presentation feasibility, content accuracy, language appropriateness, and display suitability.

The practicality stage was conducted to assess how easy and beneficial the learning media is when used in real conditions. This stage involved three science teachers and twenty 7th-grade students. The practicality of the media was evaluated based on several aspects. For the STEM Automatic Car learning media, the aspects included ease of use of tools and materials, ease of understanding the material, ease of media packaging, as well as usefulness, safety, and attractiveness. Meanwhile, for the guidebook, the evaluation aspects consisted of presentation feasibility, content accuracy, language appropriateness, and display suitability. The learning media developed includes the STEM Automatic Car learning media and its user guide, as described below.

a. STEM Automatic Car Learning Media

The STEM Automatic Car Learning Media is a media designed according to the motion topic, involving an assembly process that integrates technology. The media is provided as a kit, containing separate components according to their type. After several revisions, the final design of the media can be seen in Figure 4. The STEM Automatic Car Learning Media is a media designed according to the motion topic, involving an assembly process that integrates technology. The media is provided as a kit, containing separate components according to their type. After several revisions, the final design of the media can be seen in Figure 4.

Figure 4. Results of the Automatic Car Design



Based on Figure 4, the materials used in the development of the STEM Automatic Car learning media include a battery holder, lithium battery, motor driver, mini board, Arduino, switch, DC motor, wheels, and TCRT5000 sensor. Experiments that can be conducted using this media include assembling the components and testing its functionality for trials on travel distance and displacement, constant speed, as well as constant acceleration and deceleration.

b. User Guide for the STEM Automatic Car Learning Media

The guidebook is designed to assist students in conducting experiments. It contains an introduction to the tools and materials, procedures for assembling the media, and instructions for performing the tests. The design of the guidebook cover is shown in Figure 5.

Figure 5. Guidebook Cover Design

2. Results of the Validation Test of the STEM Automatic Car Learning Media.

The validation test was conducted by three media experts on the STEM Automatic Car learning media and its guidebook. The validation results obtained are presented as follows.

a. Results of the Validation Test of the STEM Automatic Car Learning Media

Table 10. Summary of the Validation Test Results of the STEM-Based Automatic Car Learning Media

No.	Indicator	Mean	Category
1.	Device Functionality	3,84	Valid
2.	Instructional Elements	3,72	Valid
3.	Ease of Use	3,34	Valid
4.	Aesthetics and Construction	3,75	Valid
Mean		3,66	Valid

Based on the Table 10, , the validation results yielded an average score of 3.66, indicating that the automatic car media has successfully met the required standards for device functionality, instructional elements, ease of use, and aesthetics. Following the validity criteria where a score of ≥ 3 is categorized as valid, this STEM-based automatic car learning media is declared Valid based on the experts' assessment. However, Several suggestions were provided by the validators, as follows:

1) The visual appearance of the car is still relatively basic and lacks aesthetic appeal for users.

2) The colors of the cables between components are not uniform, making it difficult to identify the wiring paths.
3) The car uses a color sensor that results in suboptimal movement, making it difficult to design an appropriate track during the testing process

Several adjustments were incorporated to address the experts' concerns, detailed as follows:

1) Enhancing the aesthetic appearance of the automatic car to make it more visually appealing to users.
2) The wiring colors were standardized across similar components (for example, between components A1 and A2) to ensure consistency and facilitate easier system identification during assembly and use.
3) In addition, the car was modified to use a reflective infrared sensor, which is commonly employed to detect lines or objects based on light reflection. This modification allows the creation of line tracks that enable the car to follow a defined path during operation.

b. Findings from the Validation of the STEM-Based Automatic Car Learning Media Guidebook

Table 11. Summary of the Validation Test Results for the STEM-Based Automatic Car Learning Media Guidebook

No.	Indicator	Mean	Category
1.	Presentation Feasibility	3,84	Valid
2.	Content Feasibility	3,74	Valid
3.	Language Feasibility	3,33	Valid
4.	Visual Feasibility	3,67	Valid
Mean		3,65	Valid

Based on Table 11, all assessed aspects of the STEM-based automatic car learning media guidebook achieved a score of ≥3, indicating that they fall within the Valid category. The overall average score of the guidebook validation reached 3.65, which confirms that the guidebook meets the criteria for a valid level of validity. However, Several suggestions were provided by the validators, as follows:

1) The material directly addressed technical content without an adequate introductory section.
2) The assembly procedures were still general or insufficiently detailed.

3) And the equipment specifications were not included.

Several adjustments were incorporated to address the experts' concerns, detailed as follows:

1) Restructuring the material through the addition of an Introductory Chapter that outlines the objectives and essential background information.
2) The instructional aspect was strengthened by clarifying the step-by-step assembly guidelines to prevent user confusion.
3) Technical information in the guidebook was improved by transparently presenting complete specifications of the tools and materials used.

3. Practicality Test Results of the STEM-Based Automatic Car Learning Media

The practicality test was conducted by three science teachers and twenty students of SMP Negeri 1 Pekanbaru, involving the STEM-based automatic car learning media and its accompanying guidebook. The practicality results obtained from the evaluation are presented as follows.

a. Practicality Test Results of the STEM-Based Automatic Car Learning Media

Table 12. Summary of the Practicality Test Results of the STEM-Based Automatic Car Learning Media

Indicator	Practicality test results (%)		Category
	Teacher	Student	
Ease of Use of Tools and Materials	96,75	90,75	Very Practical
Ease of Understanding the Learning Materials	86,00	90,00	Very Practical
Ease of Equipment Packaging	91,75	87,50	Very Practical
Usefulness, Safety, and Attractiveness	91,75	91,25	Very Practical
Mean	91,56	89,88	Very Practical

Based on Table 12, all assessed aspects of the STEM-based automatic car learning media achieved a practicality percentage of ≥76%, indicating that they fall into the Very Practical category. The overall average practicality score of the media was classified as Very Practical, with final average percentages of 91.56% based on teachers' evaluations and 89.88% based on students' evaluations.

b. Practicality Test Results of the STEM-Based Automatic Car Learning Media Guidebook

Table 13. Summary of the Practicality Test Results of the STEM-Based Automatic Car Learning Media Guidebook

Indicator	Practicality test results (%)		Category
	Teacher	Student	
Presentation Feasibility	93,75	90,75	Very Practical
Content Accuracy	89,00	89,50	Very Practical
Language Appropriateness	91,75	92,50	Very Practical
Visual Feasibility	91,75	93,75	Very Practical
Mean	91,56	91,63	Very Practical

Based on the data in Table 13, the practicality test results for the guidebook cover four main aspects: presentation feasibility, content accuracy, language feasibility, and visual design. The results show that the guidebook achieved a high practicality mean of 91.56% from teachers and 91.63% from students. As these percentages significantly exceed the established practicality threshold, the guidebook is categorized as very practical and is considered highly feasible as a supporting tool for student experimental activities.

Despite these positive results, several improvements were made based on expert suggestions. These include adding detailed descriptions for the functions of each component and incorporating realistic images to assist students during the assembly process. These revisions were implemented to ensure that the guidebook provides clearer guidance for students when working on the automatic car project.

Following the revision process, the STEM-based automatic car and its guidebook are confirmed to be both valid and practical, ensuring they are feasible and user-friendly for classroom use. Although this study focuses on validity and practicality, the implementation process demonstrated the media's potential to foster students' Higher-Order Thinking Skills (HOTS). This was evident as students analyzed and evaluated their designs after testing the device and successfully created their own tracks for the automatic car to navigate. These findings align with previous research suggesting that STEM-integrated learning media whether virtual or physical effectively enhances students' critical thinking abilities (Ariyatun & Octavianelis, 2020; Fitriyani et al.).

D. Conclusion

The development of the STEM-based automatic car and its accompanying guidebook has been successfully executed using the 4D framework. This research confirms that the Arduino-based prototype is both feasible and user-friendly, satisfying rigorous technical and pedagogical standards through expert validation. The high practicality reported by teachers and students further demonstrates that this media is effectively applicable for real-world classroom instruction. Beyond its basic functionality, the tool serves as a significant platform to foster students' higher-order thinking skills through hands-on problem-solving. Ultimately, this media successfully bridges the gap between theoretical physics and practical technological application. Future research should focus on integrating more advanced sensors to explore complex physical phenomena across broader educational contexts.

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