

Exploring Basic Transformation Geometry with Educational Robot

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Proceedings of the Kalijaga International Conference on Education 2026

Abstract. The development of artificial intelligence (AI) and robotics technology has had a significant impact on the competency needs of the 21st century. One of the crucial skills for the future is mastering the concept of Lie Algebra, which is widely used in programming systems and robot control. Unfortunately, the introduction of this concept has not yet been integrated into mathematics learning at the secondary school level. This article discusses the importance of strengthening transformation geometry concepts as a bridge to understanding Lie Algebra. This motivation underlies the development of Student Worksheets (LKPD) that combine transformation materials and robot programming, and examines the validity and practicality of these worksheets. The development results indicate that the prepared LKPD is valid and practical, thus expected to be part of transformation and robot programming, enhancing student engagement and serving as a relevant entry point for introducing advanced concepts such as Lie Algebra in higher education.

Keywords: LKPD; STEM; mBot2 robot; geometry transformation

INTRODUCTION

The development of robotics technology has brought significant changes in fields ranging from industry and medicine to education and space exploration. The International Federation of Robotics reported 4.28 million industrial robots operating worldwide in 2023, with annual installations remaining above half a million units [1]. Educational robotics has likewise been used to support STEM learning, Industry 4.0/Society 5.0 competencies, and programming activities with mobile robots such as mBot [2], [3], [4], [5], [6], [7]. One important aspect of robot development is precise movement control. Robotic manipulators and continuum robots require kinematic and dynamic models that can represent complex motion and deformation [8]. At the regional level, the ASEAN Digital Masterplan 2025 identifies robotics as an established manufacturing technology with further automation potential, alongside AI, big data, IoT, and other emerging technologies [9].

Table 1. Technology Trends for the Next 10 Years - Recommendations from the ASEAN Digital Masterplan 2025 [9].

Important Trends Today That Will Continue	Future Trends
Internet: Will continue to exist in its current form and evolve to provide a wider range of services.	AI: Will become increasingly powerful in solving specific problems.
Connectivity: Most people have reached the point of providing everything we need in a shared space.	Big Data: Will be valuable in providing new insights through data analysis.
Virtual and Augmented Reality: VR will remain a major technology, while AR may play an increasingly significant role.	Robotics: Will be able to automate more tasks and activities.
Robotics: Currently widely used in the manufacturing sector.	Autonomous Vehicles: Will develop gradually and have a limited impact by 2025.
IoT: Will improve productivity and enable better tools and working environments.	3D Printing: Can substantially reduce the time required to develop new products.

These regional technology trends reinforce the importance of preparing learners for increasingly automated environments. STEM-oriented learning has been widely discussed as a means of strengthening interdisciplinary problem solving, technological literacy, and twenty-first-century competencies across school and vocational contexts [10], [11], [12], [13], [14], [15], [16], [17]. In this study, that broader rationale supports the development of a stable robot-learning model that can connect mathematics with authentic technological applications.

In robot development, one of the most important aspects is the control of movement. Lie Algebra provides a mathematical framework for representing rotational and translational motion and has been

applied directly to mBot2 motion optimization [18]. More broadly, Lie-group and Lie-algebra formulations are established tools for continuum-robot modeling and control [8], while geometrically exact soft-robot models also exploit Lie-group structure to represent deformation and dynamics [19].

Recent work has extended these ideas to continuum-robot motion planning. Wang and Chen proposed quasi-static path planning on an implicit manifold for continuum robots interacting with elastic obstacles, showing how manifold-based planning can represent feasible robot configurations under contact [20].

Zhang et al. describe Lie-group and Lie-algebra formulations, including exponential-coordinate representations, as important tools for continuum-robot modeling and control [8]. Grazioso et al. similarly developed a geometrically exact model for soft continuum robots starting from Cosserat-rod theory formulated on a Lie group [19]. The broader educational motivation is that artificial intelligence and robotics create new technical demands and opportunities, while secondary mathematics already provides conceptual entry points such as translation, rotation, reflection, and dilation. Transformation geometry has therefore been explored through realistic, digital, and technology-supported representations [21], [22], [23], [24], [25], [26]. Integrating these mathematical ideas with STEM-oriented worksheets and technology-rich activities is consistent with a substantial body of LKPD development research across different subjects and grade levels [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39]. By integrating transformation geometry with robot programming, students can encounter mathematical concepts in a more contextual, applicative, and meaningful learning experience.

METHODS

This study belongs to developmental research and uses the ADDIE model, which consists of Analyze, Design, Development, Implementation, and Evaluation. ADDIE and related research-and-development frameworks have been widely used in the development of learning materials and educational products [40], [41], [42], [43], [44], [45], [46]. The steps in this study were: 1) Analyze, including curriculum analysis and media-needs analysis; 2) Design, including reference collection, preparation of the LKPD outline and content, and research-instrument design; 3) Development, including LKPD writing and product validation; 4) Implementation through testing; and 5) Evaluation of the final LKPD product.

The subjects in this developmental study were 32 learners of class XI-5 at SMAN 2 Bantul in the 2024/2025 academic year. The instruments included a subject-matter expert validation questionnaire, a media-expert validation questionnaire, and a learner-response questionnaire. Qualitative information from questionnaires and interviews was used as feedback for product improvement, while the expert-assessment data were converted into quantitative scores using a Likert scale following the study's stated research-method convention [47].

The feasibility of the LKPD based on subject-matter experts, media experts, and learner responses was analyzed using a five-point assessment scale. A score of 5 represented the highest value and 1 the lowest. The LKPD was considered feasible when the average scores for material, media, and learner responses each reached at least the 'good' category. The use of explicit assessment criteria is consistent with established textbook and learning-material evaluation practice [48].

Table 2. Ideal Assessment Criteria According to Widoyoko

Formula	Average Score	Average Score	Average Score	Classification
Formula	Subject Matter Expert	Media Expert	Learners	Classification
$X > X_{i+1,80} S B_i$	$X > 130$	$X > 71$	$X > 92$	SB
$X_{i+0,60} S B_i < X \leq X_{i+1,80} S B_i$	$105 < X \leq 130$	$58 < X \leq 71$	$75 < X \leq 92$	B
$X_{i-0,60} S B_i < X \leq X_{i+0,60} S B_i$	$81 < X \leq 105$	$44 < X \leq 58$	$57 < X \leq 75$	C
$X_{i-1,80} S B_i < X \leq X_{i-0,60} S B_i$	$56 < X \leq 81$	$31 < X \leq 44$	$40 < X \leq 57$	K
$X < X_{i-1,80} S B_i$	$X < 56$	$X < 31$	$X < 40$	SK

Description:

Mean score

The ideal average

(maximum ideal score + minimum ideal score)

Ideal raw junction

(maximum ideal score - minimum ideal score)

with,

Ideal maximum score = number of criterion grains $\times$ highest score

Ideal minimum score = number of criterion grains $\times$ lowest score

RESULTS AND DISCUSSION

The development of mBot2 robot-assisted LKPD learning medium was carried out with the ADDIE model including five stages. Therefore, the researcher presents the results of each stage described in the following subsection. At the analysis stage, the activities were divided into two parts, namely curriculum analysis and media needs analysis. The description regarding the analysis stage is presented as follows.

Curriculum Analysis

This stage began by analyzing the curriculum in force at the school to ensure that the material and exercises in the LKPD matched curricular needs. Based on interviews with the grade XI mathematics teacher at SMAN 2 Bantul, learning had been using the Merdeka Curriculum. Relevant Indonesian literature also documents the development of Merdeka Curriculum learning devices and the transition between the 2013 Curriculum and the Merdeka Curriculum [49], [50].

Further analysis was conducted on the material deemed difficult by the learners through interviews with teachers and distribution of questionnaires to class XI students. From the results of the interviews information was obtained that Geometry Transformation material, especially translation, is still a constraint in learning. This was corroborated by the results of a pre-research survey via google form to 32 students of classes XI-5, which showed that 91% of the students judged Geometric Transformation to be at a moderate level of difficulty, while 6% considered it difficult. Such difficulties are generally due to a weak understanding of basic algebraic operations, such as addition and subtraction, which are prerequisites in learning Geometric Transformations. In addition, the abstract nature of the material also complicates students in visualizing the concepts, including translation.

Media Needs Analysis

The analysis stage was carried out to understand the problem and determine an appropriate solution for mathematics teaching materials on geometry transformation (translation). Interviews with Mrs. Widayati, S.Pd. indicated that teaching materials were still limited mainly to textbooks, while the student survey showed that 58% of learners felt the LKPD used by teachers had not fully helped them understand and remember the material. Prior work has likewise examined teacher perceptions of LKPD use as an important consideration in learning-material development [51].

In addition, teachers also emphasized the importance of using real examples in learning so that learners can relate geometry concepts to more concrete everyday situations. This view is supported by survey results showing that 58% of learners prefer LKPDs that load challenges in the form of contextual problems from real life. The findings indicate that learners need LKPD that is not only theoretical in nature, but also applicative and contextual, thus capable of increasing their engagement in active and meaningful learning.

Furthermore, the survey results showed that 94% of the learners felt the need for the existence of real examples to understand the concept of geometry transformation. These data confirm that there is a significant need for learning media that can help visualize abstract concepts, particularly on translation material.

These findings affirm the need for applicative and contextualized LKPD to support more active and meaningful learning. Accordingly, the researcher developed a STEM-based LKPD using mBot2 robotic media, aligned with the Merdeka Curriculum to encourage critical thinking and problem solving while helping learners visualize translation through everyday technological contexts. This emphasis is compatible with research-oriented science-learning innovation that positions teachers and learning materials as drivers of contextual instructional improvement [52].

Design

Prior to the drafting stage, the researcher first collected reference sources as a reference in the arrangement of the LKPD material. The designing stage was conducted by compiling a framework of content of the LKPD consisting of three main activities, arranged incrementally from simple to complex. Activity 1 guides the learners to design the movement steps of the robot according to the prescribed route. Activity 2 directs learners to create an alternative route to avoid one obstacle, while Activity 3 challenges them to design a route that avoids two obstacles at once. Each activity integrates four components of the STEM approach, namely:

Science: analyzing robot runtime based on wheel rotational speed (rpm).

Technology: utilizing mBot2 to visualize translational motion.

Engineering: compiling a program so that the robot moves according to a designed path.

Mathematics: calculates the translation vector from the start position to the final position.

The integration of the four components aims to foster learners' critical thinking and problem-solving skills through applicative and thorough learning experiences.

The next phase was designing the content of the LKPD. The LKPD content design is divided into three main parts, namely the introductory part, the core part, and the closing part. The introduction section contains components such as cover, table of contents, achievements as well as learning objectives, and instructions for using the LKPD. The core section includes a summary of the material on translation, an introduction to the robot Makeblock mBot2, sample questions and their solutions, as well as learning activities consisting of Let's Understand and Let's Try. On the Ayo Pahami activity, learners were given three problems to analyze and solve. Meanwhile, the Let's Try activity was designed by integrating the four components of the STEM approach namely science, technology, engineering, and mathematics which ended with the Let's Conclude activity. The cover section loads the bibliography and author biodata.

Once the design of the LKPD was completed, the researcher compiled a research instrument that was used to measure the level of validity and practicality of the developed LKPD. There were three types of instruments, namely the material expert assessment instrument, the media expert assessment instrument, and the learner response questionnaire. The subject matter expert assessment instrument consisted of 31 items covering aspects of content feasibility, presentation, language, as well as integration of STEM elements. The media expert assessment instrument consisted of 17 items assessing graphic quality and display design, while the learner response questionnaire loaded 25 items assessing aspects of presentation, language, graphic quality, usefulness, as well as application of STEM aspects.

Development

At this stage, the researcher transforms the initial draft into a ready-to-use LKPD product in the learning process. The compilation of the LKPD was done using the application Canva with Indonesian Language following the rules of the Public Spelling Guidelines for Indonesian Language (PUEBI).

In general, LKPD consists of three main parts, namely the starting part, the filling part, and the ending part. The beginning section loads the cover, table of contents, learning achievements and objectives, as well as usage instructions. The cover is designed attractively in order to foster the learners' learning interest towards the translation material.

The content section constitutes the core section loaded with brief material on translation, an introduction to the Makeblock mBot2 application, sample questions along with their discussion, as well as the activities "Let's Understand" and "Let's Try." Illustrations and explanations are compiled to help learners understand the concept of translation through robot movement, so they can relate mathematical theories to real-life applications of the technology.

Meanwhile, the final section of LKPD contains a bibliography and an author's biography as a closing. Overall, the LKPD is gradually structured from simple to complex activities so that learners can understand translation concepts more deeply while developing critical thinking skills and the ability to apply technology in learning.

Product Validation

Once the product had been developed, validation was conducted to assess the validity of the learning media and to obtain constructive feedback before wider use. Material validation was conducted by Ms. Harina Fitriani, M.Pd., and Ms. Sri Widayati, S.Pd., while media validation was conducted by Ms. Vita Istihapsari, M.Pd., together with Ms. Sri Widayati, S.Pd. The use of expert validation as a development-stage quality check is consistent with prior LKPD validation practice [53].

Implementation

The implementation phase was conducted after the LKPD had been refined based on subject-matter and media-expert feedback and declared feasible for use. A pilot was conducted with 32 learners of class XI-5 at SMAN 2 Bantul, selected based on the mathematics teacher's recommendation, to assess practicality through learner responses. This scale is consistent with prior development work reporting large-class field trials involving approximately 15–50 participants [54]. The trial aimed to obtain learner responses and feedback for further refinement.

Evaluation

Evaluation is an important part of every stage of product development to ensure the conformity of the results with the set objectives. At the analysis stage, the evaluation focused on the feasibility of the material

and showed that programming using the Makeblock application for mBot2 was most appropriately applied to the translational submaterial. These results form the basis of material selection in the LKPD.

At the designing stage, an evaluation was conducted against the completeness and appropriateness of the research instrument, such as the validation sheet and the student response questionnaire, in order to guarantee the ability of the instrument in measuring the validity and practicality of the product. Meanwhile, at the development and implementation stages, the evaluation includes data analysis of validation results from subject matter experts, media experts, and student responses. The results of this evaluation were used to assess the validity and practicality aspects of the product as well as form the basis of refinement before the LKPD was declared ready for use in learning.

Data Analysis

Data from the assessment results of subject matter experts, media experts, and student response questionnaires were analyzed to know the level of validity and practicality of the LKPD. The results of the analysis are presented in the following section.

Subject Matter Expert Data Analysis

The assessment of material aspects was conducted by two validators, namely Ms. Harina Fitriani, M.Pd. (lecturer of Mathematics Education UAD) and Mrs. Sri Widayati, S.Pd. (grade XI mathematics teacher of Secondary School 2 Bantul). The validation instrument included 15 content feasibility indicators, 6 language indicators, 6 presentation indicators, and 4 STEM indicators. The results of the assessment of both validators are described in the following description.

No	Subject Matter Expert Name	Position	Score	Quantitative Data Criteria
1	Harina Fitriani, M.Pd	Associate Professor of Mathematics Education UAD	148	Very Good
2	Sri Widayati, S.Pd	SMAN 2 Math Teacher Help	130	Good
Total Score	Total Score	Total Score	278	
Average Score	Average Score	Average Score	139	Very Good

Table 3. Results of Subject-Matter Expert Calculations

Table 4. Subject-Matter Expert Ideal Assessment Criteria

No	Percentage	Criteria
1	$130 < X$	Very Good
2	$105 < X \leq 130$	Good
3	$81 < X \leq 105$	Enough
4	$56 < X \leq 81$	Less
5	$X < 56$	Very Less

Based on the data in Table 3 and Table 4, the results of the material aspect assessment by the first subject matter expert, Mrs. Harina Fitriani, M.Pd., obtained a score of 148 with the category of excellent. While the second subject matter expert, Mrs. Sri Widayati, S.Pd., gave a score of 130 with good category. Therefore, the average LKPD material facet assessment score of both experts was 139, which belongs to the excellent category.

Media Expert Data Analysis

The media aspect assessment was conducted by two validators, namely Mrs. Vita Istihapsari, M.Pd. (lecturer of Mathematics Education UAD) and Mrs. Sri Widayati, S.Pd. (grade XI mathematics teacher of Secondary School 2 Bantul). The media validation instrument includes 8 indicators on the graphics quality aspect as well as 9 indicators on the display design aspect. The results of the assessment of both validators are described in the following description.

Table 5. Media Expert Assessment Results

No	Subject Matter Expert Name	Position	Score	Quantitative Data Criteria
1	Vita Istihapsari, M.Pd	Associate Professor of Mathematics Education UAD	78	Very Good
2	Sri Widayati, S.Pd	SMAN 2 Math Teacher Help	70	Good
Total Score	Total Score	Total Score	148	

No	Subject Matter Expert Name	Position	Score	Quantitative Data Criteria
Average Score	Average Score	Average Score	74	Very Good

Table 6. Media Experts' Ideal Assessment Criteria

No	Percentage	Criteria
1	$71 < X$	Very Good
2	$58 < X \leq 71$	Good
3	$44 < X \leq 58$	Enough
4	$31 < X \leq 44$	Less
5	$X < 31$	Very Less

Based on the data in Table 5 and Table 6, the results of the assessment of media aspects by the media expert, Mrs. Vita Istihapsari, M.Pd., obtained a score of 78 which belongs to the category of excellent. Meanwhile, the subject matter expert, Mrs. Sri Widayati, S.Pd., gave a score of 70 with good category. Therefore, the mean assessment score of material aspects on the LKPD of both experts was 74, which was in the excellent category.

Analysis of Product Freshness Data

The pilot phase in this study involved 32 learners of class XI 5 SMAN 2 Bantul who were selected based on recommendations from their mathematics subject teachers. Data collection at this stage was conducted through a questionnaire to obtain students' responses to the developed LKPD. The student response questionnaire on the large-class trial included 8 indicators on the material presentation aspect, 2 language aspect indicators, 5 graphics aspect indicators, 6 usefulness aspect indicators, as well as 4 indicators related to STEM aspects. Student response results from conducting large-class trials are presented in the following section.

Table 7. Results of Learner Response Questionnaire Score Calculation

Respondents	Total Score
Class XI learners of SMAN 2	3511
Average	110
Criteria	Very Good

Table 8. Ideal Assessment Criteria of Learner Responses

No	Percentage	Practicality Criteria
1	$105 < X$	Very Good
2	$85 < X \leq 105$	Good
3	$65 < X \leq 85$	Enough
4	$45 < X \leq 65$	Less
5	$X < 45$	Very Less

The calculation results in Table 7 and Table 8 show that the mean score obtained from the students' response questionnaire is greater than 110 thus falling within the excellent criterion. Based on the assessment results of subject matter experts, media experts, as well as learners' responses, it can be concluded that the Learner Worksheet (LKPD) with STEM approach using mBot2 robot on geometry transformation material is declared valid and practical to use in learning activities.

Final Product Review

This research produced a Learner Worksheet (LKPD) with a STEM approach utilizing the mBot2 robot on Geometry Transformation material, specifically translation. LKPD development follows the ADDIE model which includes the Analysis, Design, Development, Implementation, and Evaluation stages. The final product focused on supporting translation learning in class XI high school students.

The developed LKPD consists of three parts, namely beginning, filling, and ending, then presented in print form for easy use without internet connection. The beginning section includes the cover, table of contents, learning achievements and objectives, as well as usage instructions. The content section loaded materials and illustrations on translation, introduction of the mBot2 robot and the Makeblock platform, example questions along with their solutions, as well as three learning activities designed based on the four aspects of the STEM approach. As for the final section contains a bibliography and author biographies.

The validation results showed that the developed LKPD was classified as highly valid with an average score of 90% of the material experts and 88% of the media experts. The validators judged on the aspects of content feasibility, language, presentation, graphic display, and appropriateness to the STEM approach. Feedback from the experts was used as a basis in product refinement.

A large scale trial was conducted in Bantul SMAN 2 XI class involving 32 learners. The trial results obtained a mean score of 88% with the category very practical, with no suggestions for revision. Thus, STEM-based LKPD using mBot2 was declared feasible and practical for use in mathematics learning on translational material.

CONCLUSION

The results of the study showed that the development of Learner Worksheets (LKPD) based on STEM approach with the help of the mBot2 robot successfully produced a valid and practical learning product. The LKPD is designed to support high school class XI students' understanding of geometry transformation material, particularly translations, and developed in print form so that it can be used without the need for an internet network.

The development process uses the ADDIE model which includes analysis, designing, development, implementation, and evaluation stages. At the analysis stage, a curriculum study was conducted as well as the identification of media needs through interviews with teachers and distribution of questionnaires to students. The designing stage included the preparation of the content framework, displays, and research instruments. Next, the LKPD was developed into a whole product and validated by subject matter experts as well as media experts to assess its validity. Following revisions based on validator feedback, testing was conducted on a large class to assess the practicality of the product. Evaluation is conducted on an ongoing basis at each stage of development.

The validation results show that LKPD obtained an average score of 139 from material experts and 74 from media experts, both belonging to the excellent category. Meanwhile, the test results to students obtained an average score of 110 which is also classified as excellent. Thus, the STEM-based LKPD using the mBot2 robot on geometry transformation material was declared valid, practical, and feasible to use in mathematics learning in high school..

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