

Developing Van Hiele-Based Project Learning Tools through Plastic Waste Paving Block Design on Similarity Materials

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ABSTRACT: This study aimed to develop Project Based Learning (PjBL) instructional tools through plastic-waste paving block design based on Van Hiele theory that are valid and practical for learning similarity topics. The study employed a Research and Development (R&D) approach using the 4D model developed by Thiagarajan, consisting of the define, design, develop, and disseminate stages. The participants were seventh-grade students of SMP Science Quran Al Irsyad Al Islamiyyah Jember in the 2025/2026 academic year, consisting of an experimental class and a control class. Data were collected using validation sheets, observation sheets, student response questionnaires, and readability instruments. The results indicated that the developed instructional tools met the validity criteria, with validity scores of 3.76 for the teaching module, 3.67 for the student worksheet, and 3.72 for the user guide. The practicality criteria were also achieved, as indicated by a learning implementation score of 3.5 (high category), student activity of 90% (very good category), and student responses of 92% (very positive category). These findings indicate that Project Based Learning instructional tools integrating Van Hiele theory and plastic waste paving block design are valid and practical for supporting geometry learning on similarity topics through authentic project activities involving plastic-waste paving block design.

KEYWORDS: mathematical creativity, project based learning, Van hiele theory, sustainability education, paving block design, geometry learning

INTRODUCTION

Mathematics plays a crucial role in developing the logical, critical, and creative thinking skills, as well as problem-solving abilities, required in 21st-century life (Susanto & Mahmudi, 2021). One branch of mathematics that contributes significantly to the development of these skills is geometry. Geometry not only studies shapes and spatial relationships but also involves visualization, reasoning, representation, and problem-solving activities related to various phenomena in daily life (Firmansyah et al., 2022; Suwito et al., 2024). In line with the findings of Susanto et al. (2025), research-based learning can encourage students to think creatively and produce products as a form of innovation resulting from the learning process.

One of the most widely used theories to explain the development of students' geometric thinking is Van Hiele's theory. This theory explains that geometric understanding develops through five levels of thinking: visualization, analysis, informal deduction, formal deduction, and rigor (Aries et al., 2024; Yudianto et al., 2021). Each level indicates how students understand and reason about different geometric objects. Van Hiele's theory provides an important foundation for teachers in designing learning activities appropriate to students' levels of geometric thinking development. Nevertheless, the implementation of Van Hiele's theory in learning is still often limited to concept drills and routine problem-solving, thus failing to fully provide students with a meaningful learning experience.

On the other hand, Project Based Learning (PjBL) is a learning model that positions students as active participants in completing meaningful and contextual projects (Becerra-Posada et al., 2022). Through exploration, planning, design, and product creation activities, students have the opportunity to construct knowledge while developing creativity, collaboration, communication, and problem-solving skills (Becerra-Posada et al., 2022; Selimi et al., 2025). These characteristics make PjBL a promising approach for connecting geometry learning with real-world experiences that are relevant to students' lives.

One relevant context to integrate into geometry instruction is the conversion of plastic waste into paving blocks. The problem of plastic waste has become a global environmental issue that has spurred various efforts to manage and recycle plastic materials into useful products. One widely developed alternative is the use of plastic waste as a component of paving blocks, which not only contributes to reducing environmental pollution but also supports more sustainable construction practices (Ngayakamo, 2025). In



the context of mathematics education, paving blocks provide a rich geometric representation because they involve concepts of shape, size, patterns, transformations, and similarity. Through activities involving the design of paving block patterns, students can explore various design possibilities, compare relationships between shapes, and generate diverse solutions. The use of authentic contexts that link learning to environmental sustainability issues aligns with the principles of Project Based Learning, which encourages students to engage in solving real world problems (Cierniak-Emerych et al., 2026). Therefore, the development of instructional materials that integrate geometry and environmental sustainability issues through a paving block design project using plastic waste is crucial.

Based on a review of the literature, most previous studies have focused on the effectiveness of Project Based Learning in improving learning outcomes or higher-order thinking skills. Other studies have examined the application of Van Hiele's theory to improve the understanding of geometric concepts. However, research integrating Van Hiele's theory, Project Based Learning, and authentic projects based on environmental issues in the form of instructional material development remains very limited. Thus, there remains a research gap regarding how instructional materials can be designed to link the development of geometric thinking and meaningful project activities into a unified learning experience.

Based on this gap, this study aims to develop a Project Based Learning (PBL) based instructional package through the design of paving blocks made from plastic waste, based on Van Hiele's theory, for the topic of similarity. The novelty of this study lies in the development of an instructional package that integrates Van Hiele's theory, Project Based Learning, and the context of designing paving blocks made from plastic waste as an authentic project to facilitate the development of geometric thinking. Specifically, this study aims to describe the process of developing valid and practical learning tools.

MATERIALS AND METHODS

This study employs a research and development (R&D) approach using the 4D model developed by Thiagarajan, Semmel, and Semmel. This model consists of four main stages: define, design, develop, and disseminate. The 4D model was chosen because it provides a systematic procedure for developing learning tools that meet valid and practical criteria.

The product developed in this study is a PjBL based learning tool through a project to design paving blocks made from plastic waste based on Van Hiele's theory. The resulting tool includes teaching modules, student worksheets (LKM), and a user manual for the tool.

1. Development Procedure

The stages of instructional material development follow the 4D model as follows.

Define

The definition stage aims to identify learning needs and characteristics that form the basis for the development of the learning materials. Activities carried out include analysis of learning needs, analysis of student characteristics, analysis of the concept and material of similarity, analysis of learning tasks, and formulation of learning objectives.

Design

The design stage is conducted to create an initial draft of the instructional materials. Activities carried out include the development of Project Based Learning (PBL) based teaching modules, the design of student worksheets (SW), the design of a paving block project using plastic waste, and the development of research instruments.

Develop

The development phase aims to produce valid and practical instructional materials. During this phase, the materials are validated by experts, revised based on the validators' suggestions, tested for readability, pilot-tested in experimental classes, and analyzed for validity and practicality.

Disseminate

The dissemination phase is carried out on a limited basis through the distribution of the materials to schools and mathematics teachers in both print and digital formats.

2. Research Subjects

The research subjects were seventh-grade students at the Science Quran Al Irsyad Al Islamiyyah Junior High School in Jember for the 2025/2026 academic year, comprising two classes: an experimental class and a control class. The experimental class had 20 students, while the control class had 27 students, bringing the total number of research subjects to 47 students.



The experimental class used PjBL based learning tools through a project to design paving blocks made from plastic waste, developed based on Van Hiele's theory. Meanwhile, the control class used the learning tools typically employed by teachers.

3. Data Collection Techniques

Research data were collected through observation and questionnaires.

Observation

Observations were used to assess the practicality of the instructional materials by examining the implementation of the lesson and student activities during the learning process. The observations were conducted by two observers using a validated observation sheet.

Questionnaires

Questionnaires were used to obtain data regarding the validity of the instructional materials and student responses to the developed materials. The questionnaires included an expert validation form, a readability test instrument for the materials, and a student response questionnaire.

4. Research Instruments

The instruments used in this study include:

- Learning material validation sheet;
- Learning implementation observation sheet;
- Student activity observation sheet;
- Student response questionnaire;
- Learning material readability test instrument;

5. Data Analysis

Data analysis was conducted to assess the validity and practicality of the developed learning materials.

Validity Analysis

The validity of the learning tools was determined based on the results of the validators' assessments using a 1–4 Likert scale. The average validity score is expressed as the validity coefficient (V_a). The learning tools were deemed valid if they fell within the range $3 \leq V_a \leq 4$.

Table 1. Validity Categories

Score V_a	Validity Category
$1 < V_a < 2$	Invalid
$2 \leq V_a < 3$	Moderately Valid
$3 \leq V_a < 4$	Valid
$V_a = 4$	Very Valid

Practicality Analysis

The practicality of the instructional materials in this study was analyzed using three main indicators: the feasibility of implementation, student activities, and student responses. These three indicators were selected because they comprehensively represent the aspects of the materials' implementation in the classroom, student engagement during the learning process, and students' perceptions of the use of the developed materials.

The feasibility of instruction indicates the extent to which the instructional materials can be implemented in accordance with the designed syntax; student activities reflect the level of student participation in the learning process; and student responses illustrate students' acceptance and evaluation of the materials used. Thus, these three indicators provide a comprehensive picture of the practicality of the instructional materials in a real-world learning context.

A learning tool is considered practical if each indicator achieves at least a high rating for the implementation of learning, a high rating for student activities, and a positive rating for student responses. The assessment criteria for each indicator are presented in Table 2, Table 3, and Table 4.



Table 2. Learning Implementation Categories

Score I_o	Criteria
$1 \leq I_o < 2$	Low
$2 \leq I_o < 3$	Moderate
$3 \leq I_o < 4$	High
$I_o = 4$	Very High

Based on the learning implementation criteria in Table 2, the practicality assessment is further supplemented by an analysis of student activities during the learning process. Student engagement serves as a key indicator as it reflects how actively students utilize the developed learning tools. The categories of student activities are presented in Table 3.

Table 3. Categories of Student Activities

Score	Criteria
$90\% \leq P_s \leq 100\%$	Very Good
$80\% \leq P_s < 90\%$	Good
$65\% \leq P_s < 80\%$	Fair
$P_s < 65\%$	Not Good

In addition to student activities, the practicality of the learning tools was also assessed based on student responses regarding their use in learning. These responses reflect the students' level of acceptance and views regarding the developed tools. The categories of student responses are presented in Table 4.

Table 4. Categories of Student Responses

Percentage	Criteria
$85\% \leq R_s$	Very Positive
$70\% \leq R_s < 85\%$	Less Positive
$50\% \leq R_s < 70\%$	Positive
$R_s < 50\%$	Not Positive

These three indicators instructional implementation, student activities, and student responses are applied in an integrated manner to assess the practicality of the instructional materials. Based on the defined categories, the analysis of these three indicators will indicate whether the developed materials can be effectively implemented in real-world learning contexts.

RESULTS

The results of this study include the process of developing Project Based Learning (PBL) teaching materials through a project on designing paving blocks made from plastic waste based on Van Hiele's theory, as well as the results of the analysis of the validity and practicality of the materials for the topic of similarity.

1. Definition Phase

The definition stage was conducted to identify learning needs as the basis for developing the materials. Results from observations and interviews with teachers indicated that geometry instruction, particularly regarding similarity, is still dominated by lecture based methods and routine exercises, leading students to remain passive during lessons. Additionally, the use of contextual learning media remains limited, so students' opportunities to explore ideas have not been optimized.

An analysis of student characteristics indicates that most students are at the visualization and analysis stage of geometric thinking according to Van Hiele's theory. Therefore, teaching materials are needed that can facilitate the development of geometric thinking while providing a contextual and meaningful learning experience.



Based on the content analysis, the topic of similarity was selected because it has a strong connection to the activity of designing paving block patterns. The concepts of comparing size, shape, and geometric patterns in paving blocks provide students with opportunities to apply the concept of similarity in real-world situations.

2. Design Phase

Based on the results of the definition phase, a set of instructional materials was designed that integrates Van Hiele’s theory, the Project Based Learning (PBL) model, and a project on designing paving blocks made from plastic waste. The designed materials consist of teaching modules, student worksheets, and a user guide. The learning activities were structured according to the Project Based Learning syntax, combined with Van Hiele’s stages of thinking.

During the visualization stage, students observe various shapes of paving blocks used in everyday life. During the analysis stage, students identify the properties of shapes and the relationships of similarity among paving block designs. During the informal deduction stage, students compare and explain the mathematical relationships among the designed patterns. Next, students develop a paving block design made from plastic waste as a project product that serves as the final outcome of the learning process.

3. Development Stage

The development phase began with the validation of the teaching materials and research instruments by experts. The results of the validation were used to refine the materials, resulting in a product suitable for use in the classroom. The revised materials were then pilot-tested in an experimental class to assess their validity and practicality.

Validity of the Learning Tool

Based on the results of expert validation, the validity coefficient (V_a) of the learning tools was obtained, as presented in Table 6.

Table 6. Validity Coefficients of the Learning Tool

No.	Tool	V_a	Category
1	Teaching Module	3,76	Valid
2	LKM	3,67	Valid
3	User Manual	3,72	Valid

The results indicate that all teaching materials achieved validity scores within the range of $3 \leq V_a \leq 4$, thereby meeting the criteria for validity. These findings suggest that the integration of Van Hiele’s theory, Project Based Learning, and the context of paving block design can be effectively implemented in teaching materials suitable for use. In addition to the teaching materials, the validity of the research instruments was also analyzed, as presented in Table 7.

Table 7. Validity Coefficients of the Research Instrument

No	Instrument	V_a	Category
1	Device Readability Test Sheet	3,78	Valid
2	Student Response Questionnaire	3,85	Valid
3	Student Activity Observation Sheet	3,94	Valid
4	Teaching Implementation Observation Sheet	3,90	Valid
5	Interview Guide	3,56	Valid

All research instruments were categorized as valid and are therefore suitable for use in the data collection process.

4. Distribution Phase

The teaching materials, which have been validated and found to be practical, were subsequently distributed on a limited basis. The distribution took place in both print and digital formats to mathematics teachers and through MGMP forums as part of an effort to expand the use of the teaching materials.



Practicality of the Learning Materials

The practicality of the learning tools was assessed based on the implementation of learning, student activities, and student responses. Observation results showed that the implementation of learning received an average score of 3.5 and fell into the high category. Student activities reached 90% in the very good category, while student responses to learning reached 92% in the very positive category.

The findings indicate that the learning tools are easy to implement and effective in encouraging students' active engagement at every stage of the project. Students were involved in observing the shapes of paving blocks, designing patterns, discussing relationships of similarity, and producing a variety of designs based on each group's ideas.

DISCUSSION

This study aims to develop a Project-Based Learning-based teaching tool through a paving block design project using plastic waste based on Van Hiele's theory in the topic of similarity. The results of the study indicate that the developed tool meets the criteria for validity and practicality.

The validity of the instructional materials was demonstrated by the evaluators' assessment results, which classified all components of the materials and research instruments as valid. These findings indicate that the developed materials meet the criteria for content, construction, and language, making them suitable for use in instruction. This validity also indicates that Van Hiele's theory can be systematically integrated into project-based learning materials, ensuring that learning activities are not solely focused on understanding geometric concepts. The integration of the context of designing paving blocks made from plastic waste provides students with the opportunity to connect the concept of similarity to real-world problems that are relevant to their daily lives.

In the context of this study, the activity of designing paving block patterns provides students with an opportunity to explore various shapes and relationships of similarity, thereby encouraging the emergence of a wider range of mathematical ideas.

The practicality of the learning materials is evident from the high level of learning implementation, student activities that reached the "very good" category, and student responses that fell into the "very positive" category. The high levels of student activity and response indicate that the developed materials are capable of creating student-centered learning. The characteristics of Project Based Learning enable students to actively engage in the process of observing, designing, discussing, and evaluating the results of the projects they undertake. These findings align with those of Flores-Fuentes and Juárez-Ruiz (2017), who demonstrated that PjBL can enhance student motivation and engagement in mathematics learning. Through direct involvement in projects, students gain broader opportunities to build conceptual understanding both independently and collaboratively.

The improvement in students' mathematical creativity can be explained by the characteristics of Project-Based Learning, which provides students with the opportunity to generate various alternative solutions and different products. During the paving block design process, students not only solved math problems but also developed diverse design ideas based on their individual understanding. This finding aligns with Selimi et al. (2025), who reported that the integration of STEM-PBL can enhance problem-solving skills, collaboration, and the development of mathematical ideas through authentic project activities.

In addition to the characteristics of PjBL, this study applies Van Hiele's theory. Learning activities designed based on the stages of geometric thinking enable students to build understanding gradually, starting from visualization to informal deduction. When students understand the relationships between shapes through the processes of visualization and analysis, they acquire a stronger conceptual foundation for generating various design alternatives. These findings align with Hartono et al. (2025), who demonstrated that Van Hiele-based geometry instruction can enhance students' geometric thinking development. These findings are further supported by Hartono et al. (2025), who showed that Van Hiele theory-based geometry instruction can enhance students' geometric thinking development through deeper processes of visualization, analysis, and reasoning. The results of this study are also consistent with the findings of Susanto et al. (2025), who showed that students' abilities develop after participating in learning that provides opportunities to explore and generate various solutions to a mathematical problem.

One of the main contributions of this study is the use of a paving block design project made from plastic waste as a context for learning geometry. Unlike most previous studies that utilized projects to improve learning outcomes or general skills, this study integrates geometry learning and environmental sustainability issues into a single authentic project activity. This finding aligns with Cierniak-Emerych et al. (2026), who assert that Project-Based Learning has great potential to support sustainable education through student engagement in solving real-world problems. This context provides a more authentic learning experience while raising

students' awareness of the reuse of plastic waste. These findings support the view of Cierniak-Emerych et al. (2026) that Project-Based Learning has great potential in supporting sustainable education through student engagement in solving real-world problems.

Nevertheless, this study has limitations because it involved only one school with a relatively small number of participants and focused on the topic of similarity. Therefore, future research is recommended to implement the teaching materials with a larger number of participants and on other topics in geometry in order to obtain a more comprehensive picture.

CONCLUSION

This study successfully developed a Project-Based Learning (PBL) teaching package through a project involving the design of paving blocks made from plastic waste, based on Van Hiele's theory, which meets the criteria for validity and practicality. The validity of the package is demonstrated by the fact that all components of the package and research instruments received a "valid" rating. The practicality of the package is demonstrated by high implementation rates, excellent student engagement, and very positive student feedback.

Research findings indicate that the integration of Van Hiele's theory, Project-Based Learning, and a paving block design project using plastic waste can facilitate student development. In addition to enhancing students' understanding of geometry, the developed curriculum also provides a contextual, collaborative, and meaningful learning experience through its connection to environmental sustainability issues.

The novelty of this study lies in the development of a teaching tool that integrates Van Hiele's theory, Project-Based Learning, and a paving block design project using plastic waste as an authentic context. Therefore, the developed tool has the potential to serve as an innovative alternative for teaching geometry and to support sustainable education. Further research is recommended to test the tool on a larger scale and with other geometry topics.

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