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Research paper

The Use of Stone Foundation Structure and Footplate Models as Learning by Doing Media to Improve Structural Understanding and Learning Motivation; Vocational High School (SMK) Department of Building Modeling and Information Design

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ABSTRACT

Background: This study is motivated by limited understanding of building structure concepts among vocational high school students, resulting from limited instructional media and the continued dominance of conventional teaching methods. This study aims to examine the effectiveness of the Learning by Doing approach, supported by physical mock-ups of rubble stone foundation and footplate structures, in improving conceptual understanding and learning motivation.
Methods: This study employed a one-group pretest-posttest design involving 8 eleventh-grade students from the DPIB program at Vocational High School (SMK) Sunan Drajat Lamongan, selected through purposive sampling. Data were collected through essay tests, observation, and questionnaires, and were then analyzed both quantitatively (paired t-test, Cohen's d) and qualitatively.
Results: The results showed an increase in the mean score from 26.63 to 35.50 (on a 0 – 60 scale), with an effect size (Cohen's d) of 0.97, classified as large. Although the statistical increase was not significant ($p = 0.073$), the large effect size indicates a meaningful practical effect despite the small sample size. Qualitative analysis revealed a clear improvement in conceptual understanding, such as students' ability to explain the function and mechanism of basic structural components more systematically. Affectively, most students (87.5%) reported that the mock-ups were very helpful in visualizing the concepts, and all students reported increased learning motivation.
Conclusion: This model-based learning approach has the potential to serve as a cognitive bridge linking theory and practice and to contribute to increased student motivation. This medium is a promising alternative learning strategy, especially for vocational schools with limited facilities.

INTRODUCTION

Vocational education, particularly at the SMK (vocational high school) level, holds a strategic responsibility for producing skilled, work-ready, and competent human resources capable of meeting the demands of industry in the era of globalization. One of the study programs responsible for producing drafters, surveyors, and field supervisors is the Building Design and Information Modeling (DPIB) program. Graduates of this program must possess fundamental competencies, such as reading working drawings and conducting technical analysis, which are essential to every stage of the construction process (Sira, 2016). Every prospective drafter or building technician must master basic competencies in building structures. Designing safe and feasible buildings requires a strong understanding of the concepts of load, force, moment, support, and the behaviour of structural elements. Sound mastery of these competencies determines the quality, safety, and efficiency of a construction project in the field. Critical thinking skills are also essential for students, particularly vocational students, to master, as these skills help them face the challenges of the workforce (Salma et al., 2025; Husain et al., 2025). Therefore, failure to master this competency can lead to fatal consequences, including construction errors, cost overruns, and the risk of structural failure (Fuentes-Del-Burgo & Navarro-Astor, 2016).

However, evidence from many SMKs shows a gap between students' actual abilities and the required competencies. Beyond the availability of learning support, many students still have a limited understanding of these basic structural concepts because the boarding (pondok) system restricts students' access to electronic media; SMK Sunan Drajat Lamongan and many other SMKs in the region face difficulties in providing adequate instructional media. To optimize digital learning, electronic media such as computers and structural simulation software remain very limited. Meanwhile, the available handbooks generally serve only as teacher or student reference materials with textual explanations and are insufficient to provide students with a complete spatial understanding and grasp of structural mechanics. This gap is not adequately addressed by conventional teaching methods, which remain focused on lectures, theoretical assignments, and calculation exercises; such methods have proven ineffective, resulting in low critical thinking ability and low absorption of the material taught among students, and fail to bridge this gap (N. A. Hasan, Basri K, 2024).

This teacher-centered method tends to make students passive and confines them to the levels of memorization (C1) and comprehension (C2). As a result, students become confused and are unable to apply their knowledge when confronted with structural problems that differ from the examples in their textbooks. This indicates that their conceptual understanding remains weak. According to Fitri Indrayati (2017), the use of mock-up media in building construction instruction has been shown to improve learning outcomes and students' understanding of visual and spatial material. This underscores the importance of concrete media in bridging theory and practice in the classroom. Similarly, Delfero & Handayani (2020) found that mock-up media is suitable for use in teaching building section drawing, as it can increase student interaction and strengthen conceptual understanding through direct experience.

A substantial gap in understanding arises from the disconnect between real-world practice and the abstract theory taught in the classroom. Students may memorize the names of structural components, yet they often fail to see how these components work together to resist loads. Consequently, their motivation to learn declines, and learning outcomes fall short of the expected competencies. Innovative teaching methods and media are therefore needed to bridge this gap- methods that do not rely on electronic devices yet still provide a concrete and interactive learning experience. The Learning by Doing approach offers a relevant solution. In line with Norvia et al. (2023), The Learning by Doing approach is not only effective in improving conceptual understanding, but also fosters students' self-confidence and motivation through direct involvement in the learning process. This philosophy emphasizes that knowledge and skills are most effectively acquired through direct experience and reflection on the actions taken.

Given limited facilities, simple building structure models are considered the most suitable instructional medium for implementing the Learning by Doing approach. Three-dimensional mock-ups, or completed physical models, allow students to directly touch and observe structural components up close. This approach aligns with the findings of Dart, S., & Lim (2023) who showed that three-dimensional physical models can bridge conceptual and applied understanding in structural engineering education through direct experience. Such media can be easily produced using simple, inexpensive materials (such as bamboo, wire, or ice cream sticks), and require little electrical power or advanced technical expertise to operate. It is expected that implementing a mock-up-based Learning by Doing method will help transform the learning of basic structural concepts from rote memorization into an exploratory experience. By applying a load to the simple demonstration mock-up, students can observe the structure's weak points and gain a concrete understanding of the importance of load distribution, as shown by Utschig, T., Tekes, A., & Linden (2025) who found that physical interaction with models strengthens students' engineering mindset and learning motivation. This process engages motor and sensory activity, which significantly reinforces memory and conceptual understanding (Mirkouei et al., 2016).

Research by Muhammad & Estidarsani (2018) reinforces this view, showing that the use of rubble stone foundation mock-ups within a Problem-Based Learning (PBL) model can improve Vocational High School (SMK) students' understanding and critical thinking ability in construction drawing instruction. Furthermore, according to Samsudin et al. (2018), tactile observation and exploration of mock-ups help students develop conceptual understanding of building structures, as they learn through both visual and motor engagement via direct observation and physical interaction with the mock-up components. The interest and learning motivation of eleventh grade students toward structural materials is generally low, as the topic is perceived as difficult and boring. Research on a Learning by Doing method based on simple building structure mock-ups is therefore considered important and urgent. This is consistent with Handayani (2022), who confirmed that mock-up-assisted learning within a Problem-Based Learning model can enhance students' higher-order thinking skills in the topic of detailed drawings of reinforced concrete columns and beams.

Based on the description above, this study specifically aims to: (1) analyse the improvement in eleventh-grade DPIB students' understanding of building structure concepts at SMK Sunan Drajat Lamongan, specifically on the topics of rubble stone foundations, compaction (footing base course), sloof (tie beams), and footplates before and after the implementation of mock-up-based Learning by Doing instruction; and (2) describe students' learning motivation after participating in this instruction. The results of this study are expected to provide empirical evidence regarding the potential use of simple building structure mock-ups as an alternative Learning by Doing strategy for the DPIB program at SMKs with limited practical facilities and infrastructure.

METHODS

This study employed a quantitative approach using a pre-experimental method with a one-group pretest-post-test design (Sugiyono, 2020). This design was chosen instead of a quasi-experimental design with a control group because the study involved only one available (intact) class, without the possibility of forming an equivalent comparison group during the current semester. Operationally, the research design is depicted as follows:

O1 - X - O2

Where:

O1 = pretest (measurement of structural concept understanding before treatment).

X = treatment in the form of mock-up-based Learning by Doing instruction on rubble stone foundation and footplate structures.

O2 = post-test (measurement of structural concept understanding after treatment).

This one-group design allows the researcher to compare the same subjects' conditions before and after treatment, so that internal variables such as students' individual characteristics remain relatively controlled, consistent with similar studies (Norvia et al., 2023; Muhammad & Estidarsani, 2018).

Research Subjects

The study population consisted of all eleventh-grade students in the Building Design and Information Modeling (DPIB) program at SMK Sunan Drajat Lamongan during the odd semester of the 2025/2026 academic year. The research sample consisted of 8 students, comprising the entire eleventh-grade DPIB cohort for that academic year, determined through purposive sampling based on the following criteria: (1) actively enrolled in the eleventh-grade DPIB class; (2) willing to participate in the entire research process, from the pretest, treatment, and observation to the post-test and questionnaire completion; and (3) fully present during the learning session. The eleventh grade DPIB class was selected because it was the only class taking the Building Structures course with basic competencies in rubble stone foundations and footplates during the current semester; therefore, the study population and sample were identical (total sampling of the available population). The small sample size is a consequence of the actual number of students in the class and constitutes one of the study's limitations, as discussed in the limitations section.

Operational Definition of the Independent Variable

The independent variable in this study was mock-up-based Learning by Doing instruction on rubble-stone foundation and footplate structures, an instructional approach in which students act as active observers who tactilely explore (by closely observing and directly touching/handling) a completed physical model of the building's substructure, made from authentic materials (iron/framework), to gain conceptual understanding through direct experience. The intervention was implemented in a single 105-minute face-to-face learning session (09:00-10:45 WIB), divided into the following five instructional stages (Table 1):

Table 1.
Five instructional stages

No.	Instructional Stage	Research Activity	Student Activity
1	Orientation (±10 min)	The researcher conveys the learning objectives and provides an apperception, linking the material to real-world field contexts.	Students listen, ask initial questions, and complete the pretest.
2	Interactive Material Presentation/Lecture (±30 min)	The researcher presents the material through a PowerPoint presentation covering the importance of the building substructure, the three main components of the building's base (footplate, rubble stone foundation, tie beam/sloof), the function of aanstamping, and the integration of the structural components.	Students listen to the presentation and note key points from the slides.
3	Q&A on Material, Observation, and Tactile Exploration of the Mock-up (±45 min)	The researcher opens a Q&A session to clarify parts of the presented material that students have not yet understood. The researcher presents the completed mock-up of the rubble stone foundation and footplate structure, made from authentic materials (iron/framework), explaining each component (aanstamping, rubble stone foundation, sloof, footplate) along with its function and position, and facilitates a Q&A session regarding the object observed.	Students take turns observing the mock-up closely and directly touching/handling its components and ask questions about the object being observed.
4	Post-test and Questionnaire Completion (±20 min)	The researcher closes the learning session and directs students to complete the post-test and questionnaire.	Students complete the post-test and fill out the motivation/response questionnaire.

Treatment fidelity was monitored through a learning-activity observation sheet (adapted from an instructional implementation observation instrument, with the researcher serving as the instructor) and a student observation sheet completed by an observer during the learning process. These covered 10 aspects of the researcher's performance as instructor (planning, mastery of material, strategy, classroom management, communication, formative assessment, and closing) and 10 aspects of student behaviour (readiness, mental engagement, contribution to discussion, collaboration, independence, responsibility, self-reflection, use of feedback, and attitude/behaviour), rated using a Yes/Fair/No scale accompanied by descriptive notes. The observation results showed that most aspects were carried out well (rated “Yes”), with notes for improvement regarding the development of higher-order thinking (HOTS) questions and students' spontaneous participation in expressing opinions.

Operational Definition of the Dependent Variable

The operational definitions, indicators, and measurement criteria for the two dependent variables are presented in Table 2.

Table 2.
Operational Definition of the Dependent Variables

Variable	Operational Definition	Indicators	Measurement Criteria
Understanding of Building Structure Concepts	Students' cognitive ability to explain the function, working mechanism, and interrelationships among the components of a simple building's substructure (Schraw, 2012).	(1) Explaining the function of the foundation. (2) Explaining the function of aanstamping. (3) Explaining the function of the sloof. (4) Explaining the function of the footplate. (5) Explaining the importance of the substructure. (6) Integrating the relationships among structural components.	Measured using a 0-10 scoring rubric per indicator: 1). 0 = no answer/misconception. 2). 1-4 = partially correct answer without explanation of the mechanism. 3). 5-7 = correct answer with partial explanation. 4). 8-10 = correct, complete answer with explanation of the mechanism. Total raw score range: 0-60.
Learning Motivation	Students' affective drive to actively engage in mock-up-based learning, encompassing interest, engagement, and learning self-confidence (Sjukur, 2013; Nurhasanah & Sobandi, 2016).	(1) Interest in the instructional media. (2) Active engagement during the practical activity. (3) Self-confidence in understanding the material. (4) Willingness to continue/repeat a similar practical activity.	Measured using a 4-point Likert-scale questionnaire: 1 = Strongly Disagree 2 = Disagree 3 = Agree 4 = Strongly Agree Categorized as: Low (1.00-2.00), Moderate (2.01-3.00), High (3.01-4.00)

Instruments and Measurement Procedures

Understanding of structural concepts was measured using a six-item essay test, with the mapping of items to indicators presented in Table 3. Each item was scored on a 0-10 scale following the rubric in Table 1, so that the maximum possible raw total score a student could achieve was 60 (not 100, as stated in an earlier draft); this value is consistent with the maximum pretest and post-test scores in Table 5, which do not exceed 60.

Content validity of the test and questionnaire instruments was established through expert judgment by two validators (one lecturer specializing in building engineering education and one Building Structures subject teacher), who reviewed the correspondence between each item and its indicator using a qualitative review sheet (content relevance, clarity of language, and appropriateness of difficulty level); items receiving revision notes were revised before the instruments were used, following the content-validity procedure recommended by (Saifuddin Azwar, 2017)), which could be further strengthened quantitatively using Aiken's V index in future research (Srirahayu & Arty, 2018). The reliability of the essay-test instrument in this study was assessed qualitatively through consistency of scoring across time (re-scoring by the same rater), given that the limited sample size (n = 8) did not meet the minimum requirement for estimating reliability using Cronbach's Alpha; future researchers are advised to calculate reliability quantitatively using a larger sample. The learning-motivation questionnaire consisted of 4-point Likert scale items constructed based on the indicators in Table 1, and each student's score was calculated using the following mean formula:

Mean = (Total Score per Student) / (Number of Items)

The essay-test scoring procedure involved matching students' answers against key terms and mechanism explanations in the scoring rubric, conducted by the subject teacher and confirmed by the researcher to maintain scoring consistency

Table 3.
Blueprint of the Conceptual Understanding Test Instrument

Item No.	Indicator Measured	Score Range
1	Explaining the function of the foundation in transferring building loads to the ground	0-10
2	Explaining the function of aanstamping as a compacting/stabilizing layer	0-10
3	Explaining the importance of the substructure for building strength	0-10
4	Explaining the function of the sloof as a tie beam	0-10
5	Explaining the load-transfer mechanism from the sloof–foundation–footplate	0-10
6	Explaining the function of the footplate as a column-load distributor	0-10

Data Analysis

Quantitative data were analysed using a paired-samples t-test to examine the difference between pre-test and post-test scores, and effect size (Cohen's d) to determine the magnitude of the improvement in conceptual understanding in practical terms, independent of statistical significance. Effect size was chosen to complement the t-test because it is more appropriate for small samples ($n = 8$): the significance value (p) is strongly influenced by sample size, whereas effect size measures the magnitude of the difference independently of sample size (Santoso, 2010). Cohen's d effect size for paired data was calculated using the following formula:

d = (Mean post-test – Mean pre-test) / SD pooled

where SD pooled (pooled standard deviation) was calculated as follows:

$$\text{SD pooled} = \sqrt{[(\text{SD pretest}^2 + \text{SD posttest}^2) / 2]}$$

Interpretation categories followed Cohen's (1988, as cited in Santoso, 2010) criteria:
$d = 0.2$ (small), $d = 0.5$ (medium), and $d \geq 0.8$ (large).
Based on the data in Table 3:
Mean pretest = 26.63
SD = 8.21
Mean post-test = 35.50
SD = 10.07.
SD pooled = $\sqrt{[(8.21^2 + 10.07^2) / 2]} = \sqrt{84.40} = 9.19$
so that d = (35.50 – 26.63) / 9.19 = 8.87 / 9.19 = 0.97, which falls into the large category.

This large effect size indicates that, in practical terms, mock-up-based learning produced a substantial mean difference between pre- and post-treatment scores, although the significance test ($p = 0.073$) did not reach the $\alpha = 0.05$ threshold. The combination of a non-significant p-value with a large d value is a common pattern in studies with small samples (n =

8), because the statistical power of the t test is very limited at such a small sample size; in other words, an effect that is substantively meaningful may fail to reach statistical significance simply due to the limited sample size, rather than the absence of an effect. Qualitative analysis was conducted on students' essay test answers and the results of interviews/affective response questionnaires to identify patterns of understanding, misconceptions, and students' perceptions of the instructional media used.

Research Procedure

The study was conducted through the following stages, all carried out on 27 September 2025 in a single day of instruction (09:00-10:45 WIB) to control for external variables such as differences in instructor, classroom, and time allocation between stages:

Table 4.

Stages of research

Stage	Activity	Description
1	Pretest	Students completed the 6-item essay test (±10 minutes) before instruction began, as a baseline measure of conceptual understanding.
2	Treatment (Learning by Doing based on scale models)	Implementation of the interactive material presentation/lecture stage via slide presentation, Q&A on the material, and observation and tactile exploration of the mock-up (students closely observed and directly touched/handled the components of the completed mock-up, accompanied by Q&A about the object observed), as described in the Operational Definition of the Independent Variable section, lasting approximately 45 minutes.
3	Observation of student activity	Conducted throughout the treatment session by an observer using the researcher (as instructor) and student activity observation sheets to monitor implementation fidelity and student engagement.
4	Posttest	Students completed an equivalent essay test immediately after the treatment ended (±10 minutes) to measure changes in conceptual understanding.
5	Completion of motivation/response questionnaire	Students completed a Likert scale questionnaire and a brief interview regarding the advantages, engagement, and impressions of mock-up-based instruction (±10 minutes).

The instructional media used consisted of two complementary forms: (1) a slide presentation (PowerPoint) of 14 slides presenting theoretical material on the importance of the building substructure, the three main components of the building's base (footplate, rubble stone foundation with aanstamping, and sloof), and the integration of these components, used during the material-presentation stage; and (2) a completed mock-up of the rubble-stone foundation and footplate structure, made from authentic materials (iron/framework), used during the observation and tactile-exploration stage. The mock-up was brought in a completed state (it was not reassembled or constructed by the students); the researcher demonstrated and explained each component, after which the mock-up was passed around so that every student had a turn to observe it closely and directly touch/handle its components, accompanied by a Q&A session. To control for external variables, all stages were conducted by the same researcher acting as instructor, on the same day and in the same classroom, with a predetermined time allocation, and without the addition of any learning resources beyond the slide presentation, the mock-up, and the researcher's explanations during the session.

RESULTS AND DISCUSSION

This study was conducted using a 3D model-based approach, employing mock-up media to facilitate the learning process, given that initial analysis found that the boarding (pondok) system restricts students' access to electronic media; SMK Sunan Drajat Lamongan and many other Vocational High Schools (SMK) in the region face difficulties in providing adequate instructional media. To optimize digital learning, electronic media such as computers and structural-simulation software remain very limited. Meanwhile, the available handbooks generally serve only as teacher reference materials with textual explanations and are insufficient to provide students with a complete spatial understanding and grasp of structural mechanics.

The use of physical models such as mock-ups has been shown to improve engagement and spatial concept understanding in engineering fields, particularly under conditions of limited digital technology. According to Sampaio et al. (2010), 3D based didactic models can help civil engineering students understand the construction process more concretely through visualization and direct interaction with physical and virtual models. (Ku et al., 2011), similarly emphasized that the use of interactive 3D models in construction education facilitates project-based learning and enhances student collaboration. During the design stage, several activities were carried out, beginning with preparing the material and instructional media (constructing the structure); students then completed a pretest before the material was presented, the instructional method was implemented, a post-test was conducted to measure learning outcomes, and finally the data were analysed to test the effectiveness of the method.

To determine the effectiveness of action-based instruction using the foundation structure mock-up, this study used a one-group pretest-post-test design, aimed at determining the effectiveness of Learning by Doing instruction using the rubble stone foundation and footplate structural mock-up in improving students' conceptual understanding and learning motivation. This design allowed the researcher to observe changes in learning outcomes before and after the intervention, thereby providing a comprehensive picture of the extent to which the mock-up medium contributed to the process of learning to build structures at the Vocational High School (SMK) level.

Effect size (Cohen's d) = 0.97 (large category), calculated from the data in the table above using the formula d = (Mean post-test – Mean pretest) / SD pooled.

The results in Table 5 show that mock-up-based learning had a positive impact on students' cognitive achievement. The mean pretest score was 26.63 out of a maximum possible score of 60, reflecting that students' initial understanding of the foundation, aanstamping, sloof, and footplate structures was still very limited. After the learning process, the mean score increased to 35.50 on the post-test. Although this increase was not very large in nominal terms, it proved to be substantial in statistical terms: the effect-size calculation (Cohen's d) yielded a value of 0.97, which falls into the large category ($d \geq 0.8$). This large effect size is important to note because the Paired Sample T-Test on this data did not reach statistical significance ($p = 0.073$); the combination of a non-significant p-value with a large d value is a common pattern in studies with small samples ($n = 8$), because the statistical power of the t-test is very limited at such a small sample size. In other words, the effect size provides evidence that the mean difference between pretest and post-test is substantial in practical terms, even though it cannot yet be generalized statistically at the 95% confidence level. A total of 75% of students showed an increase in their scores, indicating that the instructional intervention affected the majority of students overall.

Table 5.

Descriptive Statistics of Pretest and Posttest Scores

Statistik	Pre-test Score	Post-test Score
Mean	26.63	35.50
Standard Deviation	8.21	10.07
Maximum Score	40	51
Minimum Score	17	17

The results of the Paired Sample T-Test showed a significance value of p = 0.073, indicating that the increase was not statistically significant at the 95% confidence level. Nevertheless, given that the p-value is close to the significance threshold ($p < 0.05$), this finding still warrants consideration as a signal that the intervention has the potential to improve learning outcomes if its duration, intensity, or scope of material were expanded. Furthermore, vocational education approaches generally emphasize the development of practical skills and learning experiences, so changes in the affective and psychomotor domains also deserve primary attention in the analysis, rather than focusing solely on numerical cognitive outcomes. The qualitative findings revealed a much more pronounced development in conceptual understanding than that reflected by the test scores. Students' pretest answers were dominated by shallow descriptions and misconceptions. For example, many students stated that the foundation was simply the “base of the building” without explaining the mechanism of load transfer or subsoil stability. Answers regarding the sloof were similarly simplistic, with students understanding it merely as a “connector” without recognizing its structural function as a tie beam that distributes horizontal loads and strengthens the stability of a simple house structure.

After the mock-up-based instruction, students' post-test answers showed a more comprehensive and systematic understanding. Students began to be able to explain that the foundation functions to distribute the building's load evenly to the ground, to understand the function of aanstamping as a compacting layer that prevents soil settlement, and to identify the footplate as an element that distributes the load from a column over a wider area of ground. In addition, they were able to relate the function of the sloof as the component that unifies all elements of the foundation system, enabling them to work together as a whole. Beyond improved technical understanding, students also began to demonstrate the ability to connect theoretical concepts with practical application. They were able to explain the sequence of work in foundation construction and understand the technical reasons why a given component must be installed in a particular way. This reflects the development of procedural knowledge, which is important in vocational education, as emphasized by Schraw (2012), who noted that procedural knowledge is an essential aspect of practice-based learning that supports the transfer of knowledge to real work contexts. Furthermore, research by Hartell, E., & Skog (2015) showed that engineering education emphasizing direct experience through physical models encourages students to develop systematic and reflective thinking skills, which are key to vocational learning.

Affectively, students responded very positively to the use of the mock-up in instruction. As many as 87.5% of students felt that the mock-up medium greatly helped them visualize concepts that had previously been abstract and difficult to imagine. In addition, all students (100%) reported increased learning motivation, a livelier learning atmosphere, and greater enthusiasm for the topic of building structures. Several students stated that they felt more motivated when they could interact directly with the physical medium compared to only listening to the teacher's explanation or reading a textbook. Feedback such as requests for additional practice sessions, larger mock-ups, and the inclusion of real-world case examples indicates that this instructional model not only provided a learning experience but also naturally fostered students' curiosity.

This study reinforces the view that mock-up media can function as a cognitive bridge connecting abstract theory with the realities of field construction (Komara, S., & Iskandar, 2025). The mock-up creates a visual and physical representation that helps students build understanding through direct experience (learning by doing), consistent with the principles of constructivist theory (Deddy, S. Rokhmah, 2022). Through manipulation and direct observation of the model, students come to understand not only the shape of the structure, but also the relationships among its elements, the direction of load flow, and the technical rationale behind each construction step. This experience transforms the learning process from merely receiving information into actively constructing concepts. In the context of vocational schools, this approach is highly relevant, given that vocational students tend to understand material more easily through practical application. Furthermore, model-based learning also supports the achievement of 21st century competencies, such as collaboration, technical communication, creativity, and problem solving. This model opens opportunities for the development of higher-order thinking skills (HOTS) when students are challenged to evaluate structural conditions, compare designs, or analyse installation errors.

Several limitations of this study should be taken into consideration. The absence of a control group means that this study cannot confirm that the improvement in learning outcomes was attributable solely to the use of the mock-up. The relatively small sample size, drawn from a single class, limits the generalizability of the findings. In addition, the short duration of the intervention prevented the researchers from evaluating the long-term impact of mock up use on systemic thinking ability. For future research, it is recommended that the study design be expanded to include a control group, a larger number of students, and a longer instructional duration. Combining the mock-up with problem-based or project-based learning models also holds strong potential for improving the quality of conceptual understanding and developing the 21st century skills students need.

CONCLUSION

This study shows that implementing Learning by Doing instruction through the use of a rubble stone foundation and footplate mock-up has the potential to improve SMK students' understanding of building structure concepts as well as their learning motivation, although the statistical analysis (Paired Sample T-Test, $p = 0.073$) did not show a significant increase at the 95% confidence level. The tendency toward score improvement among most students (75%), along with improved quality of qualitative responses, still suggests a potential positive effect of mock-up-based learning on students' cognitive development. These findings should therefore be interpreted as promising preliminary evidence, rather than as conclusively proven effectiveness. This concrete medium appears to play a strategic role in helping students understand technical and abstract material: after participating in the instruction, students were able to provide more coherent and accurate explanations of the function of the foundation, the mechanism of load transfer, the role of aanstamping, and the structural position of the sloof and footplate, indicating a reduction in misconceptions compared with their pretest answers.

This study nevertheless has limitations, particularly the absence of a control group, the small sample size (n = 8) drawn from a single class, and the relatively short duration of the intervention (a single learning session). Future research is therefore recommended to employ an experimental design with a control group, a larger sample size, and a longer intervention duration, in order to test the effectiveness of mock-up-based instruction more convincingly, particularly regarding conceptual understanding and higher-order thinking skills.

Overall, mock-up-based instruction on building structures demonstrates relevance and potential feasibility as an instructional strategy in Vocational High Schools (SMK), particularly under conditions of limited practical facilities. This medium is able to provide a more realistic and applicable learning experience and thus has the potential to serve as an alternative for bridging theory and practice in building engineering education.

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