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Development of a Hypothetical Learning Trajectory for Systems of Linear Equations in Three Variables Based on PMRI Using the Context of Hijab Accessories: A Pilot Experiment Study

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Abstract

This study aims to develop a Hypothetical Learning Trajectory (HLT) for the topic of Systems of Linear Equations in Three Variables (SLETV) based on Indonesian Realistic Mathematics Education (PMRI) using the context of hijab accessories supported by Information and Communication Technology (ICT). The research employs a design research method of the validation study type, consisting of three phases: preparing for the experiment, design experiment, and retrospective analysis, with a focus on a pilot experiment involving six tenth-grade students majoring in Fashion Design at SMK Negeri 6 Palembang. Data were collected through observation, interviews, and documentation, and analyzed retrospectively. The results show that the developed HLT facilitates students' understanding of SLETV concepts gradually through a process of mathematization from real-world contexts to formal mathematical forms, although some procedural errors in algebraic operations were still found. In addition, the use of the hijab accessories context and ICT support increased students' engagement in the learning process. Based on the retrospective analysis, revisions to the HLT were made in terms of scaffolding, strengthening algebraic operations, and providing more varied contextual problems, resulting in a more optimal and meaningful learning design.

Keyword: Hypothetical Learning Trajectory, PMRI, SLETV, ICT

INTRODUCTION

Mathematics plays an important role in developing logical, systematic, and critical thinking skills that are essential in daily life as well as in the workplace. In vocational education,

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particularly in Vocational High Schools (SMK), mathematics is not only studied as a foundational discipline but also as a means to support students' vocational competencies. However, in practice, mathematics learning in SMK is often still abstract and insufficiently connected to students' fields of expertise. Therefore, mathematics learning in vocational education needs to be designed in a contextual manner and aligned with students' areas of specialization (FitzSimons, 2013; Hoyles et al., 2010).

In reality, mathematics instruction in SMK tends to remain abstract and lacks contextual relevance, causing students to experience difficulties in understanding concepts deeply. One of the topics that frequently presents challenges is the System of Linear Equations in Three Variables (*SLETV*), as students are required to understand relationships among variables, construct mathematical models from contextual problems, and determine appropriate solutions. These difficulties mainly arise in mathematical modeling skills and solving word problems, which are essential aspects of algebra learning (Kafiar et al., 2015; Cahirati et al., 2020). Furthermore, limited understanding of *SLETV* may affect students' ability to learn advanced topics such as linear programming, since *SLETV* is a prerequisite concept in algebra (Usiskin, 1995; Cai et al., 2010).

Various studies indicate that students face difficulties in solving *SLETV* problems, especially in the form of word problems. These challenges include misunderstanding the problem, errors in translating problems into mathematical models, and a lack of accuracy in calculations. This is consistent with findings showing that students often struggle to interpret contextual problems and represent them appropriately in mathematical form (Cahirati et al., 2020; Jupri et al., 2016). In addition, students experience misconceptions in algebraic concepts, such as misunderstanding equivalence and symbolic manipulation, which lead to errors in the solution process (NCTM, 2014; Wijaya et al., 2018). These findings are also supported by preliminary studies conducted in this research, which show that students still have misconceptions about equivalence, make errors in algebraic operations, and struggle to construct mathematical models from contextual situations. This indicates that the current learning process has not optimally supported the development of students' conceptual understanding.

One approach that can be used to address these problems is Indonesian Realistic Mathematics Education (PMRI). PMRI emphasizes that mathematics is a human activity that should be connected to meaningful contexts for students, so that learning is not separated from their real-life experiences. This approach focuses on the use of contextual situations as a starting point for learning, helping students construct conceptual understanding gradually through a

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process of mathematization from informal situations to formal mathematical forms (Prahmana, 2017); van den Heuvel-Panhuizen & Drijvers, 2014).

Through this approach, students are given opportunities to reinvent mathematical concepts actively, so that learning is not only oriented toward procedures but also toward conceptual understanding and its connection to real-life situations. Several studies show that the implementation of PMRI can improve conceptual understanding, problem-solving skills, and student engagement in mathematics learning (Wijaya et al., 2018).

The use of contexts that align with students' experiences is one of the key elements in PMRI-based learning. Contexts that are close to students' daily lives allow them to understand mathematical concepts more easily through real and imaginable situations (Wijaya et al., 2018). For students in vocational schools majoring in fashion design, creating hijab accessories is an activity closely related to their daily experiences. This activity involves various aspects that can be mathematically modeled, such as the number of beads, color variations, and combinations of materials used. The use of contexts relevant to students' fields of expertise has been shown to increase engagement and conceptual understanding, as students can see the direct connection between mathematics and their vocational practices (Fitriani & Zulkardi, 2021; Sembiring et al., 2010). Therefore, the context of making hijab accessories can serve as a bridge to help students understand *SLETV* concepts in a more concrete and meaningful way.

In addition, the use of Information and Communication Technology (ICT) in learning can support students' understanding. The use of technology in mathematics learning has been proven to improve learning quality and help students understand abstract concepts through visual and interactive representations (Hillmayr et al., 2020; Tokac et al., 2019). Video-based media, for example, can present information in both visual and audio forms, making it easier for students to understand complex concepts. Research shows that the use of instructional videos can improve conceptual understanding and learning outcomes, as they provide a more engaging and accessible learning experience (Noetel et al., 2021; Kay, 2019). Therefore, integrating ICT into mathematics learning is expected to enhance student engagement and facilitate a more interactive and meaningful learning process.

Although many studies have examined the use of PMRI in mathematics learning, research that specifically develops a Hypothetical Learning Trajectory (HLT) for particular topics using relevant contexts is still limited. Several studies indicate that developing HLT within the design research framework plays an important role in describing students' thinking processes and facilitating meaningful learning through contextual activities (Cobb & Gravemeijer, 2006; Bakker, 2018). In addition, PMRI-based research is generally conducted through design research

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stages, including preparing for the experiment, design experiment, and retrospective analysis, where the experimental phase (including pilot experiments) is used to test and revise the learning trajectory design before it is implemented on a larger scale (Gravemeijer & Cobb, 2006; Bakker, 2018). This process allows researchers to analyze students' thinking and refine learning designs iteratively based on empirical data obtained during the experiment.

However, studies that specifically integrate the development of PMRI-based HLT with specific vocational contexts and ICT support are still limited. Therefore, research is needed not only to examine learning effectiveness but also to develop learning trajectories that systematically represent students' thinking processes in mathematics learning. Based on this background, this study aims to develop a Hypothetical Learning Trajectory (HLT) for *SLETV* based on PMRI using the context of creating hijab accessories supported by ICT and to test it through a pilot experiment study. The results of this study are expected to contribute to the development of more contextual, meaningful, and relevant mathematics learning designs for vocational high school students.

METHOD

This study employs a design research method of the validation study type, which aims to develop a Hypothetical Learning Trajectory (HLT) for the topic of Systems of Linear Equations in Three Variables (SLETV) based on Indonesian Realistic Mathematics Education (PMRI). This method is chosen because it allows for an in-depth investigation of the learning process and enables the improvement of instructional design through iterative cycles (Bakker, 2018; Cobb & Gravemeijer, 2006).

The study consists of three main phases: preparing for the experiment, design experiment, and retrospective analysis. In the preparing for the experiment phase, the researcher conducted a literature review, analyzed students' difficulties, and designed the Hypothetical Learning Trajectory (HLT) along with the instructional materials. The design experiment phase aims to test the designed learning trajectory through classroom implementation. Meanwhile, the retrospective analysis phase is conducted to analyze the data obtained during the experiment in order to revise and refine the learning trajectory (Gravemeijer & Cobb, 2006; Bakker, 2018).

The study was conducted with tenth-grade students majoring in Fashion Design at SMK Negeri 6 Palembang. In this article, the research focuses on the design experiment phase, particularly the pilot experiment, which involved six students in a small group. This phase aims

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to test and revise the designed learning trajectory before it is implemented on a larger scale (Bakker, 2018).

Data were collected through observation of students' activities during the learning process, interviews to explore students' strategies and understanding, and documentation in the form of students' work. The collected data were then analyzed retrospectively by comparing the actual learning process with the designed learning trajectory. The results of this analysis were used to improve and refine the instructional design to make it more optimal (Cobb & Gravemeijer, 2006).

For experimental research, the type of research design used should be clearly stated in this section. The types of data, data collection methods, instruments, and data collection procedures also need to be described in detail. It is important to interpret the obtained data and explain their relevance to the research problems and objectives.

RESULTS AND DISCUSSION

The research findings are presented in the form of graphs, tables, descriptive explanations, or other formats that facilitate understanding of the data obtained. Analysis and interpretation of these results are conducted prior to the discussion.

The study was conducted with six tenth-grade students majoring in Fashion Design at SMK Negeri 6 Palembang during the pilot experiment phase. The learning activities were carried out using a Hypothetical Learning Trajectory (HLT) based on Indonesian Realistic Mathematics Education (PMRI) with the context of creating hijab accessories supported by ICT. The researcher acted as the teacher, while the learning process was observed to examine students' responses and strategies in understanding the concept of Systems of Linear Equations in Three Variables (SLETV).

During the pilot experiment, learning was implemented through several activities designed to help students gradually understand SLETV concepts, starting from situational contexts to formal mathematical forms.

Activity 1: Understanding the context of hijab accessories

In this activity, students were asked to observe a video about mathematical art and create hijab accessory designs. The results showed that most students initially did not understand the concept of mathematical art and were only familiar with simple geometric shapes. After being given stimulus through video, students began to create simple designs such as triangular patterns and numerical arrangements. However, the designs produced were still

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relatively simple, as students were not yet accustomed to integrating mathematical concepts with aesthetics. This can be seen in Figure 1.

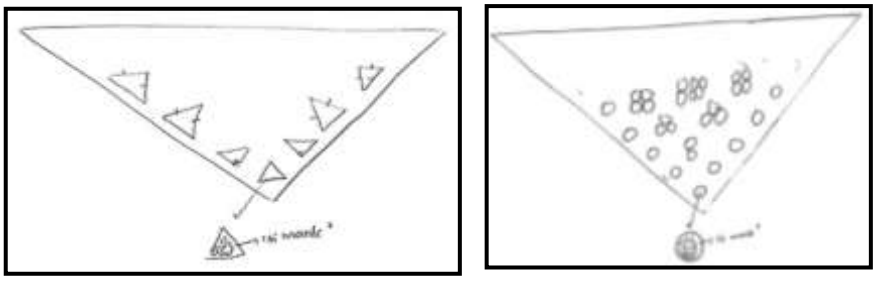


Figure 1. Mathematical art designs created by students

The designs produced by students consisted of simple patterns, such as Pascal's triangle and variations of triangular shapes. One student used several types of triangles right triangles, isosceles triangles, and equilateral triangles which were planned to be placed along the edges of the hijab according to the fabric width. This indicates that students were still at the situational level, where they understood the context concretely before moving toward mathematical representation. This stage represents the initial phase of mathematization in PMRI learning, where students begin with real situations before progressing to formal forms (van den Heuvel-Panhuizen & Drijvers, 2014). This finding is supported by interview results, where a student stated, "I only knew shapes like triangles and circles; I didn't know they could become mathematical art."

Activity 2: Creating hijab accessories

In this activity, students created hijab accessories using beads based on their designs. Students worked in groups and began to understand the relationship between design, number of beads, and pattern regularity, as shown in Figure 2.



Figure 2. Students' activities in creating hijab accessories using beads

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Students arranged beads one by one to form mathematical art patterns on the hijab. During this process, they considered the alignment between the initial design and its implementation on the fabric, such as determining pattern size, whether it remained the same or required scaling. They also paid attention to color arrangement and positioning to maintain symmetry. However, observations showed that students still had difficulties maintaining consistency in size and proportion. This indicates that students were still in the context exploration stage, an early phase in PMRI learning where students interact with real situations before constructing mathematical models. At this stage, students began horizontal mathematization by connecting real contexts to initial representations, although they were not yet able to form formal mathematical models (van den Heuvel-Panhuizen & Drijvers, 2014).

Activity 3: Constructing mathematical models and solving SLETV

In this activity, students solved SLETV problems based on previous activities, such as calculating the number of beads of each color and the total used. Students modeled the problem into a system of equations by assigning variables (e.g., x, y, z) to each color. They also combined information from other groups to form three equations, which were solved using elimination and substitution methods.

To help students recall the concept of solving systems of linear equations in two variables (SPLDV), ICT support in the form of an instructional video was used. Through this video, students were able to review the steps of elimination and substitution before applying them to systems of linear equations in three variables (SLETV). The results of students constructing mathematical models can be seen in Figure 3.



Figure 3. Students' responses in constructing mathematical models

The students' work (Figure 3) shows that most students were able to construct mathematical models from the given information. This indicates that they had reached the initial stage of problem solving, namely understanding the problem and planning a mathematical model. However, at the stage of solving systems of linear equations in three variables (SLETV), procedural errors were still found, as shown in Figure 4.

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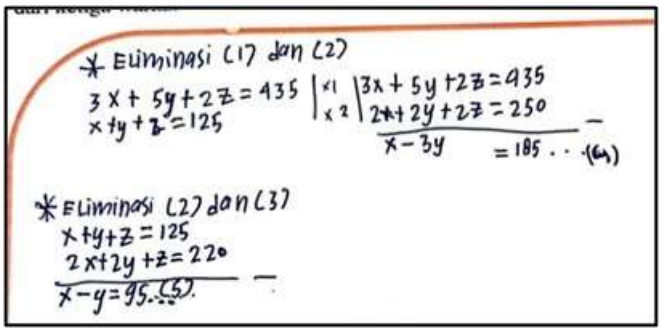


Figure 4. Students' procedural errors

However, errors occurred in algebraic operations, for example writing $5y - 2y = -3y$instead of $3y$. Although their strategy was appropriate, these mistakes show a lack of accuracy in calculations. This finding aligns with previous studies indicating that vocational students often experience difficulties in algebraic manipulation, negative signs, and numerical operations. This suggests that students had reached vertical mathematization, but not yet optimally, due to symbolic manipulation errors (van den Heuvel-Panhuizen & Drijvers, 2014).

The students' work in Figure 4 shows that they were able to apply the elimination method in solving systems of linear equations in three variables (SLETV) by eliminating the variable z from two equations. They also understood the initial procedural step, namely equalizing coefficients before performing elimination.

However, there was an error in the algebraic operation process, particularly in subtracting variable coefficients. The student wrote $5y - 2y = -3y$, whereas it should be $5y - 2y = 3y$. This error led to the formation of an incorrect equation and affected the final result.

Nevertheless, the solution strategy used by the students was appropriate, namely eliminating variables step by step until obtaining an equation with two variables. This indicates that students understood the basic procedure for solving SLETV, but still experienced difficulties in calculation accuracy. This finding is consistent with previous studies showing that vocational high school students tend to make errors in equation manipulation, the use of negative signs, and numerical operations due to incomplete conceptual understanding (Asfyra et al., 2026). Furthermore, this condition indicates that students have reached the stage of vertical mathematization, but it has not yet developed optimally due to errors in symbolic manipulation (van den Heuvel-Panhuizen & Drijvers, 2014).

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Activity 4: Solving contextual SLETV problems

In this activity, students solved SLETV word problems presented in the context of Fashion Design and daily life. Students worked in groups to understand the problems, construct mathematical models, and solve the SLETV.

The results show that most students were able to correctly formulate mathematical models from the given information. In the first problem, students were able to construct three equations based on the context and proceed to solve them using elimination and substitution methods (Figure 5).

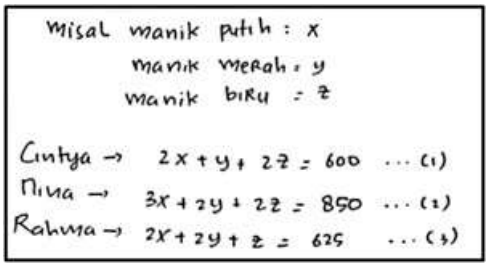


Figure 5. Students' written equations

However, procedural errors were still found in the calculation process, such as mistakes in multiplying coefficients during elimination, which led to incorrect final results, as shown in Figure 6.

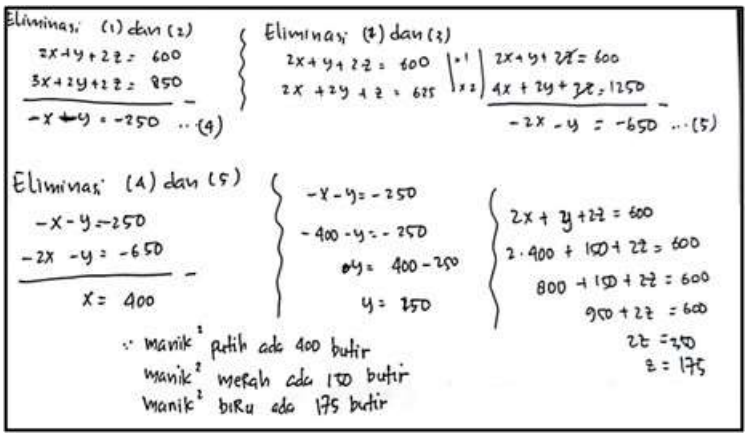


Figure 6. Students' procedural errors in the elimination process when solving SLTEV

Based on Figure 6, students attempted to solve the system of linear equations in three variables (SLETV) using elimination and substitution methods. Students appeared able to determine the initial steps by eliminating variables from several equations. However, during the elimination process between equations (2) and (3), a procedural error occurred in the algebraic operation. The student multiplied the third equation by 2 but made an error in multiplying the

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coefficients, particularly in the *y* component, resulting in an incorrect equation. This error affected the final solution outcome.

Nevertheless, the strategy used by the students was appropriate, namely eliminating variables step by step to obtain simpler equations. This indicates that students understood the solution procedures but still experienced difficulties with calculation accuracy. This type of error falls into the category of procedural errors (process skills errors), which occur when students understand the concepts and solution steps but lack precision in performing calculations (Jupri & Drijvers, 2016). Furthermore, this condition shows that students have reached the stage of vertical mathematization, although it has not yet developed optimally due to errors in symbolic manipulation (van den Heuvel-Panhuizen & Drijvers, 2014).

However, some students still experienced difficulties in understanding the meaning of the problem, particularly in translating information into mathematical models. This indicates that students' ability to comprehend word problems still needs improvement. Overall, this activity shows that students were able to perform the mathematization process from real contexts to formal mathematical forms. This is consistent with Polya's problem-solving stages: understanding the problem, planning a solution, carrying out the plan, and reviewing the result (Polya, 1973). In addition, the use of real-life contexts in the problems supports the principles of PMRI, where context serves as a bridge for understanding mathematical concepts (van den Heuvel-Panhuizen & Drijvers, 2014).

Retrospective Analysis

Based on the pilot experiment, a retrospective analysis was conducted by comparing the designed Hypothetical Learning Trajectory (HLT) with the actual learning process.

In Activity 1, students began to recognize the concept of mathematical art through video support. However, the designs produced were still simple because students tended to choose easy patterns. This indicates that students were still at the situational stage, where understanding is limited to concrete contexts (van den Heuvel-Panhuizen & Drijvers, 2014).

In Activity 2, students were able to implement their designs into hijab accessories, but they still experienced difficulties in determining size and proportion. This indicates that students were still in the context exploration stage and had not fully connected visual representations with mathematical models.

In Activity 3, most students were able to construct mathematical models from the given context, indicating that they had reached the stage of horizontal mathematization. However,

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errors in algebraic operations particularly in manipulating positive and negative numbers were still found, which fall into procedural errors (process skills errors) (Jupri & Drijvers, 2016).

In Activity 4, students showed improvement in solving contextual SLETV problems. However, some students still had difficulties in constructing mathematical models from word problems and lacked accuracy in calculations.

Overall, the designed learning trajectory was able to help students understand SLETV concepts gradually, from real contexts to formal representations. However, improvements are needed in the stages of mathematical modeling and strengthening algebraic operation skills to support optimal development of vertical mathematization.

Revision of the Hypothetical Learning Trajectory (HLT)

Based on the results of the retrospective analysis, the designed HLT needs to be revised to improve learning effectiveness.

In Activity 1, revisions were made by adding more varied examples of mathematical art designs and providing additional stimuli so that students do not only choose simple patterns. This aims to encourage exploration of ideas and creativity in linking mathematical concepts with aesthetic contexts, in line with the principles of contextual learning in PMRI (Wijaya et al., 2018).

In Activity 2, additional scaffolding is needed in the form of guidance for determining size and proportion when transferring patterns onto hijab fabric. This scaffolding is important to help students bridge visual representations with real implementation, as gradual support has been shown to enhance conceptual understanding in contextual mathematics learning (Putra et al., 2024).

In Activity 3, revisions focus on strengthening algebraic operation concepts, particularly in manipulating positive and negative numbers. More structured solution examples and additional exercises are also needed to minimize procedural errors. Although students were able to construct mathematical models, errors in algebraic operations indicate that their difficulties are not only procedural but also conceptual. This suggests that students tend to apply procedures without deep conceptual understanding, as also reported in previous studies on vocational students (Asfyra et al., 2026). The use of ICT-based learning videos can also be optimized to strengthen conceptual understanding, as digital media have proven effective in helping students understand abstract concepts through visualization (Hillmayr et al., 2020).

In Activity 4, more varied contextual problems and guided questions should be added to help students construct mathematical models from word problems. This approach aligns with

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research showing that guided questions can improve students' mathematical modeling abilities in solving contextual problems (Widjaja, 2019).

Overall, the revision of the HLT emphasizes scaffolding, strengthening fundamental concepts, and enhancing the connection between context and mathematical models. These revisions are expected to help students develop mathematization processes more optimally, both in horizontal and vertical stages.

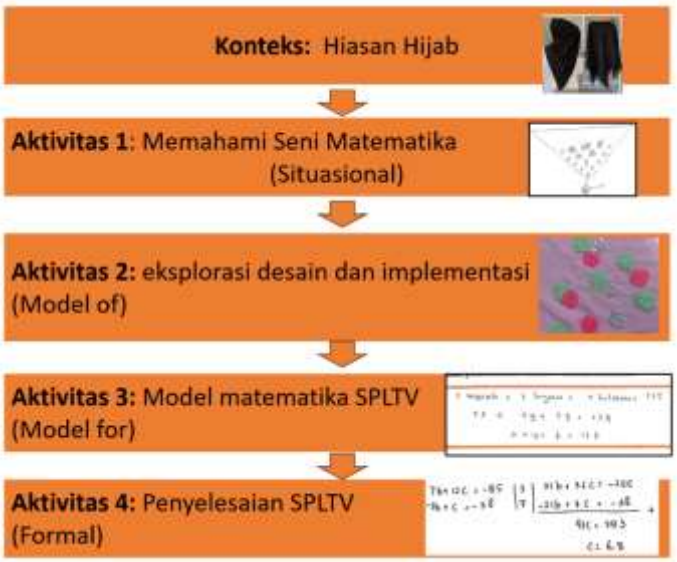


Figure 7. A PMRI-based Hypothetical Learning Trajectory (HLT) for SLETV using the context of hijab accessories

Figure 7 shows the PMRI-based Hypothetical Learning Trajectory (HLT) for SLETV using the context of hijab accessories. The trajectory begins at the situational stage, followed by the model of, model for, and finally the formal stage. This process illustrates students' gradual mathematization from real-world contexts to formal mathematical representations.

CONCLUSION

Based on the research findings, the PMRI-based Hypothetical Learning Trajectory (HLT) for SPLTV using the context of hijab accessories supported by ICT is able to help students understand SPLTV concepts gradually, from the situational stage to the formal stage through the process of mathematization. Students were able to construct mathematical models and solve SPLTV problems, although procedural errors in algebraic operations and difficulties in modeling word problems were still found. The results of the retrospective analysis indicate that the

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designed HLT is generally appropriate; however, improvements are needed in terms of scaffolding, strengthening fundamental concepts, and providing more varied contextual problems. Therefore, the resulting HLT can be used as an alternative instructional design that is contextual and meaningful, particularly in mathematics learning in vocational high schools.

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