A Local Instruction Theory (LIT) for Teaching Linear Equation in One Variable Through STEM Instruction using a Dynamo-Powered Toy Car

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A Local Instruction Theory (LIT) for Teaching Linear Equation in One Variable Through STEM Instruction using a Dynamo-Powered Toy Car

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Abstract
The results of the preliminary study show that students still experience obstacles in learning mathematics. These obstacles occur because the designed learning is not able to facilitate student learning trajectories, thus causing low learning outcomes. This research aimed at designing and developing a learning trajectory for the linear equations in one variable material as a systematic set of activities through Science, Technology, Engineering, and Mathematics (STEM) instruction using dynamo-powered toy car. This design is referred to as a Local Instruction Theory (LIT) in teaching the linear equations in one variable material. The research method used is the method of design research, following the stages of preliminary design, teaching experiment, and retrospective analysis. The research subjects in the teaching experiment were grade VII students of a state junior high school in Bandung City. Data were collected from a variety of sources, namely student worksheet, teacher and student observation sheet, documentation, interview, and video recording of the learning course. This study analyzes the validity of the research through a qualitative research perspective and reliability refers to the quality of the research itself. The results of the research described the performance of the LIT-based design for linear equations in one variable learning in STEM instruction in four meetings. The research was concluded with the generation of one local instruction theory that is valid, practical, and effective to guide a set of instructional activities to build understanding of the linear equations in one variable material through STEM instruction using dynamo-powered toy car.

Keywords: design research; dynamo-powered toy car; linear equation in one variable; STEM.

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Introduction

In mathematics learning, it is important to pay attention to learning trajectories in order to achieve the learning goals. Learning trajectories are an illustration of a student's thoughts during the learning process that takes the form of conjectures and hypotheses of a set of learning designs developed to foster the student's thinking development in order for the goals of learning to be achieved (Clements & Sarama, 2004). They represent regularly expected predispositions that evolve through empirical experience and are designed to identify the steps possibly taken by the student to develop mathematical ideas; it should be noted that the trajectories are unique to every student (Sztajn et al., 2012). Learning trajectories support the teacher in modelling the student's thoughts, identifying specifically what the student needs to learn next, and interacting with the student during the teaching (Wilson et al., 2014).

The learning process that takes into account learning trajectories is generally built by a local instruction theory (LIT). LIT itself is a special theory that guides and assists the student to learn a certain topic/material with a learning scope, instrument, or medium in a detailed, graduated, and specialized manner for the topic/material in question (Gravemeijer, 2004a). LIT can be used by the teacher as a framework of reference to reach a goal by considering the assumption on the student's mathematical preparation (Nickerson & Whitacre, 2010; Larsen, 2013). The LIT construct developed in a research design context indicates the teacher's reference for designing instruction with a teaching material focused on a concept, taking into consideration the difficulty faced by the student, anticipating all possible responses of the student, and making mathematical instruction more meaningful (Gravemeijer, 2004b).

One of the mathematical topics/materials many students still find difficult to learn is linear equations in one variable (Amerom, 2002). This difficulty of the students to learn the linear equations in one variable material is partly caused by a jump in the students' thinking way from an arithmetic way of thinking to algebraic one, causing it difficult for them to understand the symbols and the meaning of the equation mark, as well as by the students' dependency upon procedural knowledge (Magruder, 2012; Rohimah, 2017). Especially for the latter, the students have a difficulty to solve linear equations in one variable as they only have a procedural understanding, so they find it difficult to understand forms of algebra and solve mathematical operations (Jupri et al, 2014a). Such a particular difficulty stems from the teacher's teaching method that relies only on formula memorization to understand the concepts (Zulkardi, 2002; Jupri, 2015). Therefore, it is deemed necessary to design an LIT that contributes to the learning and teaching process to tackle the difficulty to understand concepts appropriate for the students' cognitive development (Dorier & Sierpinska, 2001; Carcamo et al., 2019).

In the 21st century, such a teacher's teaching method as mentioned above is regarded as lacking relevance with the current development. The extremely rapid development of science and technology triggers increased competences across state borders, leading to the world's globalization. A reform of education is done by a number of nations by developing STEM (Science, Technology, Engineering, and Mathematics) education. STEM offers a solution to take on the challenges of the 21st century (Bybee, 2013). In this research, STEM instruction was designed and implemented for the linear equations in one variable material using a dynamo-powered toy car simulation. The teacher designed instruction based on STEM education using a dynamo-powered toy car as the medium. It was expected that the STEM instruction for the linear equations in one variable material that used a dynamo-powered toy car could overcome or minimize the difficulty previously discovered. In addition, 21st-century skills were also imprinted onto the learning goals for the students to have a meaningful learning experience (Crispin et al., 2019).

Set against such a backdrop, this research was to explain the LIT for linear equations in one variable through STEM instruction using a dynamo-powered toy car. Specific questions that were explored included the advantages and contributions of STEM learning using dynamo-powered toys and learning strategies applied to junior high school students. The main novelty are:

1. STEM-based mathematics learning using a dynamo-powered toy car
2. Especially for teaching linear equations in one variable in junior high school
3. Lesson plan

Methods

This research used a design research method. Design research itself is a systematic study to design, develop, and evaluate an instruction as a solution to a problem (Plomp & Nieven, 2007). It involves the steps of preliminary design, teaching experiment, and retrospective analysis (Gravemeijer, 2004a). The overall steps involved in this research are illustrated in Figure 1.

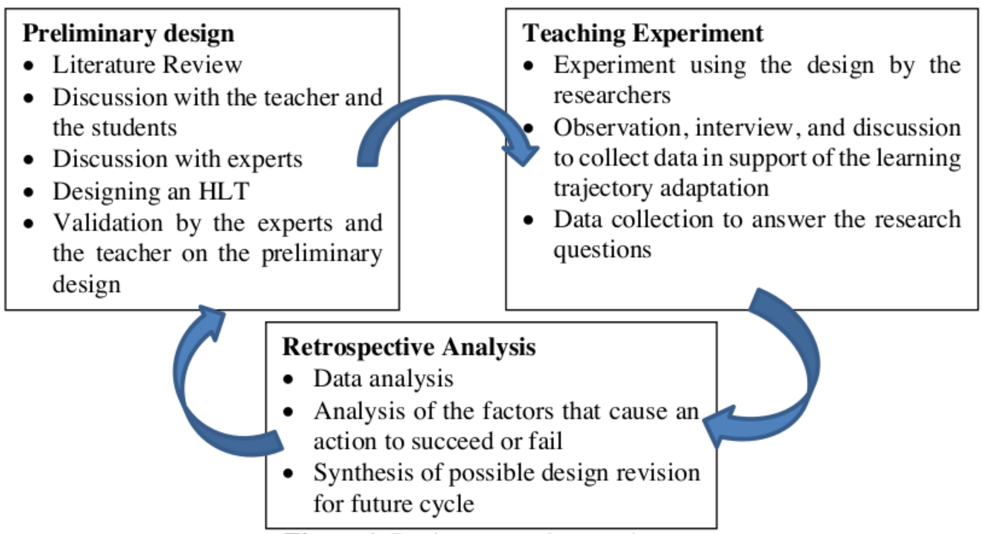

Figure 1. Design research procedure

As illustrated in Figure 1, the preliminary design step was commenced with the designing of the hypothetical learning trajectory (HLT) for STEM instruction to support the students in integrating mathematical instruction with other instructions, especially the instructions of science, technology, and engineering. To this end, a dynamo-powered toy car was used to integrate the concept of linear equations in one variable into a simulation of straight-line motion with constant velocity. In the experiment step, instruction was carried out in four meetings through both synchronous and asynchronous learning using Zoom meeting and WhatsApp group, respectively. The research subjects involved in the teaching experiment were 50 class VII students of a state junior high school in Bandung. Data were collected from a range of sources, namely student worksheets, teacher and student observation sheets, documentation, interview, and video recording during the learning process. Then, the retrospective analysis step was carried out by comparing the results of observation during the learning process against the HLT.

The data analysis used is video analysis of the learning process and student interaction in the classroom based on the structure of students' thinking and its relation to the concepts presented by the teacher and analysis of student learning outcomes. This study analyzes the validity of the research through a qualitative research perspective that can be trusted (Denzin & Lincoln, 2009) and reliability refers to the quality of the research itself (Sarosa, 2012). Confidence in this research is seen from four things, as follows:

1. Credibility is done by using triangulation of written documents in the form of field notes, student worksheets, and learning video recordings. Next, conduct follow-up interviews with participants and allow them to comment on learning outcomes.
2. Transferability is done by transferring the findings to context, namely detailed analysis of interview transcripts, observations, and document notes, using theory and purposive sampling, and presenting short and logical theoretical propositions accompanied by examples of relevant data.
3. Firmness in research conducted by external auditors to obtain an assessment objective, accuracy of research data, level of data analysis, and matters relating to the formulation of the problem.
4. Confirmability is the extent to which research results are based on research objectives by means of researchers making the research process as transparent as possible by clearly describing how the data was collected, the procedures carried out during the research, analysis, and theory.

Results

STEM analysis on mathematics learning in the implementation of One Variable Linear Equation (PLSV) material is described in Table 1.

Table 1. STEM Analysis on Linear Equation in One Variable Material

Science	**Technology**
Apply the concepts of displacement, distance, time, and speed.	1. Internet to find information related to learning materials 2. Computer for making reports
Engineering	**Mathematics**
1. Design, engineer, and use a dynamo-powered toy car. 2. Testing, making improvements, and communicating the results of the dynamo-powered toy car simulation.	Linear equation in one variable material.

Furthermore, An HLT is designed and developed for each learning activity that is undertaken by the students. The lesson plan and the students' learning flow during the learning process are inseparable from the learning trajectory of each student. Therefore, the hypothetical learning trajectory of the student was developed in the HLT designed. The learning activities designed are described below.

Goal 1: The students use the walk activity to define linear equations in one variable

Learning activities:

- Student activity of walking from one point to another point at home
- Students would then write down their travelled distance, displacement, and travel time
- Students can write down the difference between distance and displacement
- The result generated by one of the students after performing the walking activity, drawing their walking route, and writing down their traveled distance, displacement, and travel time in Figure 2.

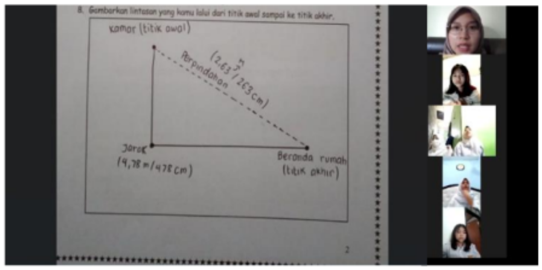

Figure 2. Student result activity in Student Work Sheet-1

- Students distinguish and write examples of closed sentences and open sentences from the simulation results that have been written
- The teacher guides the students in concluding the understanding of the linear equations in one variable from the activities that have been carried out by students.
- Students can define linear equations in one variable

Allegations of students' way thinking:

- The path passed by students can be in the form of triangles, straight paths, circles, semi-circles, and other irregular shapes
- Students measure the traveled distance and displacement by using a measuring meter, counting the number of tiles passed on the floor of the house, or other methods that make it easier for students to measure
- If the path taken by students is a straight line then the traveled distance and displacement will be the same
- Anticipation: The teacher compares the simulation results of students with different trajectories so that students can find differences in distance and displacement. The teacher directs students to write in the form of closed and open sentences.

Goal 2: The students develop ways to solve linear equations in one variable

Learning activities:

- Students was to observe an athletic championship and then write down the travelled distance, the champion, the runner-up, the travel times, and the running velocities of the champion and the runner-up.
- Students determined the time taken by the champion and the runner-up to arrive at the same position using the relative velocity formula.
- Students solved a linear equation in one variable using this relative velocity formula

Allegations of students' way thinking:

- Students play the video many times to find the same position between the champion and the runner-up
- Anticipation: the teacher directs students to solve problems from concrete to formal with a one-variable linear equation solving procedure

Goal 3: The students develop a way to solve linear equations in one variable with fractions

Learning activities:

- Students observing a jogging problem that was presented on the student worksheet
- Students were to write down the velocity, distance travelled, and total travel time

- Determine the length of the jogging track using the velocity formula
- Student solved a linear equation in one variable with fractions by multiplying by the denominators' least common divisor or by completing the fraction operation first

Allegations of students' way thinking:

- The fraction concept was extremely difficult for the students, especially for those who had yet to understand the counting operation for fractions
- Anticipation: The teacher guides and directs students in solving fractional operations on one-variable linear equations and the structure of one-variable linear equations with fractions.

Goal 4: The students use a dynamo-powered toy car to apply the linear equations in one variable concept

Learning Activities:

- Students assembling a dynamo-powered toy car and using it for a simulation

Step 1 | Step 2 | Step 3

Figure 3. Dynamo-powered toy car simulation

- Figure 3 depicts the steps in the dynamo-powered toy car simulation in order from the first step to the last: 1) assembling the dynamo-powered toy car; 2) starting up the simulation by running the dynamo-powered toy car; and 3) wrapping up the simulation by setting the dynamo-powered toy car to a stop.
- students then filled out a simulation observation table containing the distance travelled, travel time, and velocity for the simulation
- Students analyzed the results of the dynamo-powered toy car simulation
- Students wrote the coordinates of some points and drew a velocity-distance graph out of the simulation conducted
- students found an application of the linear equations in one variable concept by writing down the equation for the graph, which was a linear equation in one variable, and drawing a conclusion on the linear equations in one variable application in the simulation
- The results of the dynamo-powered toy car simulation is linked to the linear equations in one variable concept by drawing a velocity (along the x-axis)-distance (along the y axis) graph, resulting in a linear equation in one variable, as was the answer of one of the students in Figure 4.

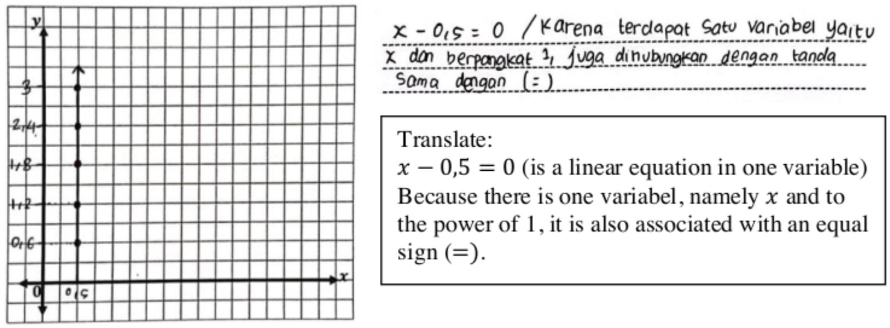

Figure 4. The graph and equation resulted from the dynamo-powered toy car simulation

Allegations of students' way thinking:

- The mathematical equation resulting from the dynamo-powered toy car simulation of each group of students was presented
- Feedback and group discussion in this step provided a thing to reflect on from the simulation that the students had performed
- The experience from this STEM instruction came as of use to the students in building up their self-confidence in learning mathematics
- Anticipation: Re-check the results of student simulations so that the results that will be made in graphs are in accordance with the learning objectives, namely to produce a graph of a one-variable linear equation

At the end of the lesson at the fourth meeting, a posttest was conducted to check the achievement of student learning outcomes. The achievement of student learning outcomes can be seen in Table 2 and Figure 5.

Table 2. Categories of Achievement of Learning Outcomes

Achievement	Category	Jumlah	Presentase
$s > 70$	High	41	82%
$60 \leq s \leq 70$	Medium	5	10%
$s < 60$	Low	4	8%

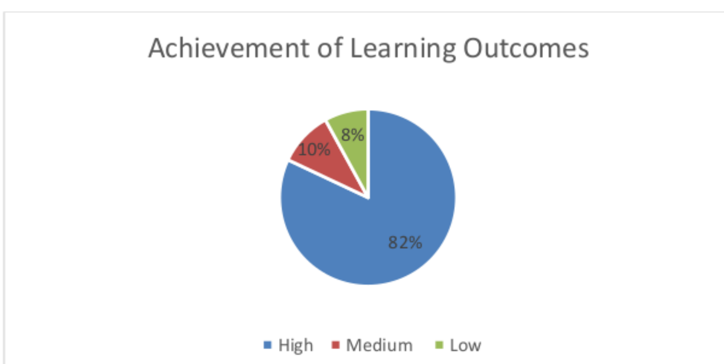

Figure 5. Achievement of Learning Outcomes

Discussion

Based on research result and teacher's experience at school, the researchers anticipated that, when the students were involved in an activity, they would demonstrate a stronger understanding of the material (Nickerson & Whitacre, 2010). In first goal, the students were involved in an activity, this algorithm would make sense to the students. The result generated by one of the students after performing the walking activity, drawing their walking route, and writing down their travelled distance, displacement, and travel time can. The distance and displacement concepts involved in this walking activity could foster motivation, creativity, and innovation in the creation of a technology (Suwarma et al., 2015).

To arrive at this second goal, the researchers commenced by posing a reasonable problem in a real-world context to enable the students to count and estimate in an authentic situation (Pramuditya, et al, 2021). The activity performed by the students was to observe an athletic championship and then write down the travelled distance, the champion, the runner-up, the travel times, and the running velocities of the champion and the runner-up. Then, the students determined the time taken by the champion and the runner-up to arrive at the same position using the relative velocity formula. Using this relative velocity formula, some students solved a linear equation in one variable formally and some others did informally. When posed with a real-world problem, the students, using their experience, would come up with a variety of ways to solve linear equations in one variable (Koedinger et al., 1997). The two solving methods were used to bridge the students' thinking process from arithmetic to algebraic. The progression in the students' understanding from informal to formal made the learning process meaningful to the students (Saraswati et al., 2016). Additionally, the problem presented in the second meeting was related to contextual algebra, allowing the students' mathematical process to run well (Jupri et al., 2014a).

The third goal was to be reached by presenting a narrative naturally arising real-life problem as an opportunity to solve a sub-standard problem in the context of a written procedure (Saenz, 2009). The activity conducted in the third meeting was the students observing a jogging problem that was presented on the student worksheet. The students were to write down the velocity, distance travelled, and total travel time. Then, they were to determine the length of the jogging track using the velocity formula. The conclusion from the student activity in the third meeting was that the students solved a linear equation in one variable with fractions by multiplying by the denominators' least common divisor or by completing the fraction operation first. The difficulty in solving linear equations in one variable lied in the operations of fractions and the structure of linear equations in one variable with fractions (Jupri et al., 2014b).

The fourth goal is that students can apply linear equations in one variable concept in relevance with daily life phenomena through a simulation using a dynamo-powered toy car. This activity was conducted to develop a model for informal activity through a local change into a model for a more formal activity (Gravemeijer, 1999). The experience from this STEM instruction came as of use to the students in building up their self-confidence in learning mathematics and science (Hayward, 2016).

Overall, this design research was started with posing some problems, followed by concept analysis and finding the right solutions to solve such problems. The solutions proposed were realized in concrete in student activities as defined by the HLT (Drijvers, 2003). The HLT was finally summarized in a table containing a set of student activities the students were to undergo, the mental activities expected, and the role of STEM instruction that used dynamo-powered toy car. The teacher played a role in determining the variance of instruction according to the learning trajectory of each student (Johan, 2008). The HLT in this research emerged as a LIT on linear equations in one variable concept and can be seen as a concrete form of local instruction theory (Gravemeijer, 1999). The integration of STEM in this research is as follows:

science was represented by the concepts of distance, displacement, travel time, and velocity; technology was represented by the use of video recording through QR code and URL over the Internet; engineering was represented by the engineering involved in the assemblage of the dynamo-powered toy car, and mathematics was represented by the linear equations in one variable concept.

Conclusion

Resulted of the learning trajectory development in this research was a valid, practical, effective local instruction theory (LIT) on the linear equations in one variable material for class VII of junior high school through STEM instruction using a dynamo-powered toy car. The LIT on the linear equation in one variable material can be used by the teacher to develop an instruction that is oriented toward the fulfillment of 21st-century skills. The sequencing of the key topics in learning of linear equations in one variable through four-meeting STEM instruction was as follows: 1) defining closed sentences, open sentences, and linear equations in one variable; 2) solving linear equations in one variable; 3) solving linear equations in one variable with fractions, and 4) applying linear equations in one variable using a dynamo-powered toy car. With a mindset on four goals, a valid, practical, effective LIT was established to guide a set of instructional activities to build an understanding of the linear equations in one variable material through STEM instruction using a dynamo-powered toy car.

The development of STEM-based learning has a weakness if the material taken is difficult to integrate into the STEM component. LIT on linear equation in one-variable material through STEM learning in this study would be better if applied to students with the same characteristics. With the characteristics of students who are much different, learning needs to be conditioned with students' previous knowledge. Recommendations from the findings of this study for practitioners so that STEM-based mathematics learning can be used in the learning process and effectively achieve good student learning outcomes. For groups of teachers or policymakers to organize STEM training that focuses on mathematics.

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Conflicts of Interest

All authors do not have conflict of interest in regard to this research or its funding.

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