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A local instructional theory (LIT) for teaching linear equation through STEM instruction

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Abstract

Several previous types of research showed that students had obstacles in understanding the concept of linear equations. These obstacles occur because the designed learning cannot facilitate student learning trajectories, thus causing low learning outcomes. This research aimed to design and develop 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 a dynamo-powered toy car. This design is referred to as a Local Instructional 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 various sources, namely student worksheets, teacher and student observation sheets, 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 survey itself. The research results 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 instructional theory that is valid, practical, and effective in guiding 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.

Keywords: design research; dynamo-powered toy car; linear equations in one variable; local instructional theory; STEM

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Introduction

It is essential to pay attention to learning trajectories in mathematics to achieve the learning goals. Learning trajectories illustrate 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 for the learning goals to be achieved (Clements & Sarama, 2004). They represent regularly expected predispositions that evolve through practical 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 modeling the student's thoughts, identifying precisely what the student needs to learn next, and interacting with the student during the teaching (Wilson et al., 2014).

The learning process that considers learning trajectories is generally built by a Local Instructional Theory (LIT). LIT itself is a particular theory that guides and assists the student in learning a specific topic/material with a learning scope, instrument, or medium in a detailed, graduated, and specialized manner for the topic/material in question (Gravemeijer, 2004). The teacher can use LIT as a reference framework to reach a goal by considering 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, 2004).

One of the mathematical topics/materials many students still find challenging to learn is linear equations in one variable (Jupri & Drijvers, 2016). 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 an 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 (Rohimah, 2017). Especially for the latter, the students have difficulty solving 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). This difficulty stems from the teacher's teaching method relying only on formula memorization to understand the concepts (Prahmana, Zulkardi, & Hartanto, 2012). Therefore, it is deemed necessary to design a LIT that contributes to the learning and teaching process to tackle the difficulty of understanding concepts appropriate for the student's cognitive development (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 growth of science and technology triggers increased competencies across state borders, leading to the world's globalization—several nations reformed education 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 created 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).

In previous studies, the topic of linear equations in one variable was explained using algebra tiles (Saraswati et al., 2016), using the cover-up strategy applet (Jupri & Drijvers, 2016), using local wisdom (Rohmah et al., 2017), and other research-based on realistic mathematics education (Rohimah, 2017; Pramuditya et al., 2021). There has been no research on linear equations with one variable learning mathematics using STEM instruction. In addition, research on Local Instructional Theory (LIT) is still not widely studied at the junior high school level. LITs that have developed a lot include LIT in elementary school (Nickerson & Whitacre, 2010), high school (Meika et al., 2019), and at the university level (Sztajn et al., 2012; Larsen, 2013; Carcamo et al., 2019). In 21st century learning, STEM is essential to be developed in education, especially for junior high school students, accompanied by the design of learning trajectories to achieve learning goals. Therefore, the novelty in this research is a lesson plan for STEM-based mathematics learning using a dynamo-powered toy car for teaching linear equations in one variable in junior high school. Using a dynamo-powered toy car, this research explained the LIT for linear equations in one variable through STEM instruction. The explored specific questions included the advantages and contributions of STEM learning using dynamo-powered toys and learning strategies applied to junior high school students.

Methods

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

As illustrated in Figure 1, the preliminary design step was to design the hypothetical learning trajectory (HLT) for STEM instruction to support the students in integrating mathematical education with other instructions, especially in science, technology, and engineering. To this end, a dynamo-powered toy car was used to incorporate the concept of linear equations in one variable into a simulation of straight-line motion with constant velocity. A dynamo-powered toy car is a type of toy car that uses a dynamo with battery power to drive it. The experiment taught four meetings through synchronous and asynchronous learning using Zoom meetings and WhatsApp groups. The learning goal of the first meeting is that students can formulate the meaning of linear equations in one variable; the second learning goal is that students can determine the solution of a linear equation in one variable. The third learning goal is that students can solve linear equations in one variable in the form of fractions. The fourth learning objective is to apply the concept of linear equations in one variable. The research subjects involved in the teaching experiment were 50 class VII students, with 35 female students and 15 male students of a state junior high school in Bandung. Data were collected from various 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 observation results during the learning process against the HLT.

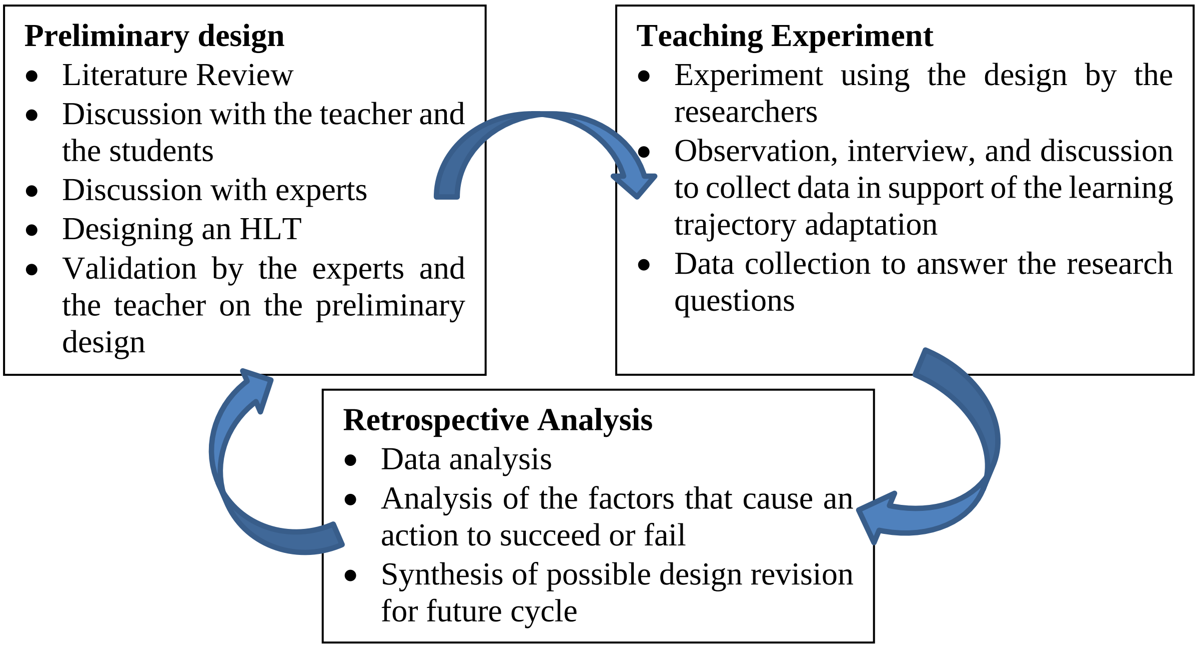


Figure 1. Design research procedure

STEM analysis on mathematics learning in the implementation of linear equations in one variable material is described in Table 1.

Table 1. STEM analysis on Linear equations in one variable material

Science	**Technology**
Apply the concepts of displacement, distance, time, and velocity.	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 dynamo-powered toy car simulation results.	Linear equations in one variable material.

HLT for STEM instruction on the linear equations in one variable material in this study can be seen in Table 2. The HLT consists of the learning goal, the hypothetical learning process, and the learning tasks.

Table 2. Summary of the HLT for STEM instruction on the linear equations in one variable

Hypothetical Learning Process	Description Task
1. Students use their knowledge to determine the concept and meaning of closed and open sentences. 2. Students determine the meaning of linear equation in one variable from an open sentence connected with an equal sign and has one variable to the power of one.	Task 1: Perform motion simulations and write down measuring distances and displacements. Next, write closed and open sentences from the measurement results and write down the meaning of linear equations in one variable.
Students determine how to solve linear equations in one variable by calculating the time of two trains passing by.	Task 2: Observe video and analyze the problem of two trains passing by. Next, find the time of two trains passing by solving linear equations in one variable.
Students are looking for a solution to a linear equation in a fractional form of the jogging problem given on the worksheet.	Task 3: Observing and analyzing jogging problems on worksheets. Next, find the length of the jogging track by solving a mathematical model of a linear equation of one variable in the form of a fraction.
1. Students apply the concept of linear equations in one variable in everyday life. 2. Students discover the concept of linear equations in one variable from the simulation results of a dynamo-powered toy car.	Task 4: Assemble and experiment with a dynamo-powered toy car by calculating its distance, time, and velocity. Next illustrates a graph of the relationship between distance and velocity. The resulting graph is a linear equation in one variable.

The data analysis used is a 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 study itself (Sarosa, 2012). Confidence in this research is seen in four things, as follows:

1. Credibility triangulates written documents in 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. Researchers make 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

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

Goal 1: The students use the walking 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 traveled distance, displacement, and travel time
- Students can write down the difference between distance and displacement
- 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 students have carried out.
- Students can define linear equations in one variable.

Allegations of students' way of 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 closed and open sentences.

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

Learning activities:

- Students observe the video and analyze the problem of two passing trains.
- Students record the velocity of the first train, the velocity of the second train, the total distance, and the departure time of the two trains.
- Students determine when time the two trains pass using the relative velocity formula.
- Students solve linear equations in one variable using this relative velocity formula.

Allegations of students' way of thinking:

- Students find the time the two trains pass informally.
- Anticipation: the teacher directs students to solve concrete problems with linear equations in one variable 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 traveled, and total travel time
- Determine the length of the jogging track using the velocity formula
- Student solved linear equations in one variable with fractions by multiplying by the denominators' least common divisor or by completing the fraction operation first

Allegations of students' way of 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 linear equations in one variable and the structure of linear equations in one variable with fractions.

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

Learning activities:

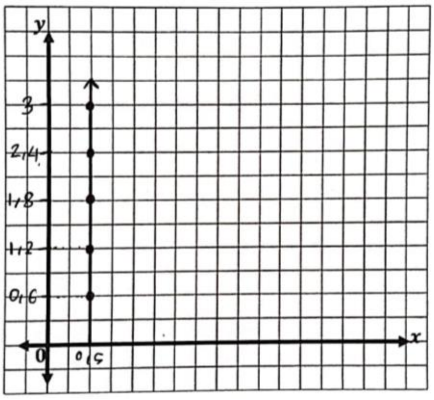
- Students assemble a dynamo-powered toy car and use it for a simulation.

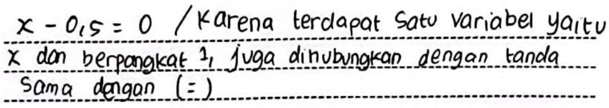
Step 1 Step 2 Step 3

Figure 2. Dynamo-powered toy car simulation

- Figure 2 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 traveled, 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 linear equations in one variable, as was the answer of one of the students in Figure 3.





Translatione:
$x - 0{,}5 = 0$ (is a linear equations in one variable)
Because there is one variabel, namely x and to the power of 1, it is also associated with an equal sign (=).

Figure 3. The graph and equation resulted from the dynamo-powered toy car simulation

Allegations of students' way of 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 by the learning objectives, namely to produce a graph of linear equations in one variable

At the end of the lesson at the fourth meeting, a post-test was conducted to check student learning outcomes. The achievement of student learning outcomes can be seen in Table 3.

Table 3. Categories of achievement of learning outcomes

Achievement	Category	Number of Respondents	Percentage
$s > 70$	High	41	82%
$60 \leq s \leq 70$	Medium	5	10%
$s < 60$	Low	4	8%

In Table 3 above, the data for the achievement category of post-test results of students included in the high category of 82%, medium category 10%, and low category 8%. The data in Table 3 does not show in detail the student scores one by one, but the average student score from the results of the final test of this study is 86. Therefore, the average student achievement is in the high category.

Discussion

Based on research results and teachers' experience at school, the researchers anticipated demonstrating a more robust understanding of the material (Nickerson & Whitacre, 2010). In the first goal, the students were involved in an activity; this algorithm would make sense. One of the students generated the result after performing the walking activity, drawing their walking route, and writing down their traveled distance, displacement, and travel time can. This walking activity's distance and displacement concepts could foster motivation, creativity, and innovation in creating a technology (Suwarma et al., 2015).

To achieve this second goal, the researcher begins by posing a problem that makes sense in a real-world context to enable students to calculate and estimate in an authentic situation (Pramuditya et al., 2021). The activities that students do are watching videos and analyzing the problem of two trains passing by, then writing the velocity of the first train, the velocity of the second train, the total distance, and the departure time of the two trains. Then, students determine when the time the two trains pass using the relative velocity formula. Using this relative velocity formula, some students formally solve linear equations in one variable, and some informally. When posed with a real-world problem, the students, using their experience, would come up with various ways to solve linear equations in one variable (Koedinger & Aleven, 2016). 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 (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 wrote down the velocity, distance traveled, and total travel time. Then, they were to determine the length of the jogging track using the velocity formula. The student activity in the third meeting concluded that the students solved linear equations 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 lay in the processes of fractions and the structure of linear equations in one variable with bits (Jupri et al., 2014b).

Conclusion

The learning trajectory development in this research was a valid, practical, effective local instructional 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 teacher can use the LIT on the linear equations in one variable material to develop an education-oriented toward fulfilling 21st-century skills. The sequencing of the critical topics in learning 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 good, practical, effective LIT was established to guide instructional activities to understand 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 challenging to integrate into the STEM component. In this study, LIT on linear equations in one variable material through STEM learning would be better applied to students with the same characteristics. With the features of students who are much different, education 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 teachers or policymakers, to organize STEM training that focuses on mathematics.

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Conflicts of Interest

The authors declare that no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely by the authors.

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