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Pedagogical Content Knowledge In Teaching Systems of Linear Equations: A Case of Secondary School Mathematics Teachers

Marhami[1], Jarnawi Afgani Dahlan[2*], Dadan Dasari[3]

[1,2,3]Pendidikan Matematika FPMIPA Universitas Pendidikan Indonesia

e-mail: jarnawi@upi.edu

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Abstract

This study aims to examine the Pedagogical Content Knowledge (PCK) of teachers in teaching the Two-Variable Linear Equation System (TVLES) material. A descriptive qualitative approach was employed, involving three mathematics teachers who taught TVLES to eighth-grade junior high school students. Data were collected through semi-structured interviews as well as analysis of instructional portfolios, including lesson plans, worksheets, and teaching materials related to TVLES. The interview protocol consisted of ten questions based on the five components of PCK: orientation to teaching, curriculum knowledge, knowledge of students' understanding, knowledge of instructional strategies, and knowledge of assessment. The data analysis followed the stages of data collection, reduction, presentation, verification, and conclusion drawing. Data validity was ensured through time triangulation and the use of multiple data sources. The results revealed that teachers demonstrated adequate competency in three PCK component (orientation to teaching, knowledge of students' understanding, and assessment knowledge), while curriculum knowledge and instructional strategies remained underdeveloped. Based on these findings, it is recommended to establish collaborative forums and provide ongoing mentoring to help teachers enhance their curriculum knowledge and instructional practices. Curriculum developers should also ensure that teachers have sufficient resources and support to implement TVLES materials effectively in the classroom.

Keywords: pedagogical content knowledge; secondary school; two-variable linear equation system

1. Introduction

The Two-Variable Linear Equation System (TVLES) is one of the compulsory materials taught at the junior high school level. This is in accordance with Permendikbud Number 22 of 2016, where one of the competency standards for junior high school students is to understand TVLES and use it in solving problems. Paujiah & Zanthy (2020) state that in order for students to be able to understand TVLES and use it in problem solving, they must first understand the topics of Linear Equations of Two Variables (TVLE) and Straight Line Equations (SLE).

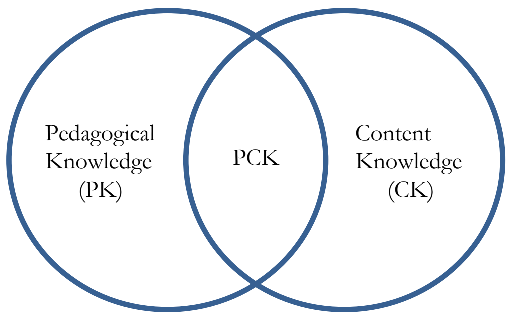
TVLES material is very important because it relates directly to real everyday life (Wu, 2016). TVLES is a system or unity of several linear equations of two similar variables. The linear equation of two similar variables referred to here is the equation of two variables that contain the same variable. TVLES problems can be solved using 5 methods: the graphical method, substitution, elimination, the inverse matrix, and Cramer's rule (Deogratias, 2022). However, at the secondary school level, the methods taught are limited to 4 methods, namely the graphical method, substitution, elimination, and the combined method.

TVLES is often confusing for students because it is the first time they have encountered manipulating two equations to solve for two variables (Cai et al., 2010). The material for a system of two-variable linear equations has a fairly high level of difficulty, so many students have difficulty solving problems (Kolo et al., 2021). There are several studies that discuss the difficulties in TVLES material experienced by students, such as research by Rifadena & Hidayanto (2021) which found that students did not understand the meaning of the questions, so they could not represent the information in the questions in symbolic and visual form. This is because students have difficulty building knowledge about how to understand problems so they are able to solve them (Amelia et al., 2018; Nuraeniah et al., 2022; 2021; Putri & Manoy, 2013).

The ability of students to solve TVLES problems is inseparable from how the teacher, as a determining factor for success in the learning process, must have in-depth knowledge and understanding of the material that will be taught (Aminah & Wahyuni, 2018). A teacher who has good knowledge and the right way of teaching will help students more easily build their understanding of the material presented. This ability is a must for a teacher, especially for math teachers, so that they are able to provide an understanding of abstract material that can be easily absorbed by students (Kwong et al., 2007). Besides mastering the mathematics content being taught, a mathematics teacher is also highly expected to have the ability to teach the content or material to his students. One important component that must be mastered by a teacher in this case is the Pedagogical Content Knowledge component, commonly abbreviated as PCK. In the implementation of classroom learning, the teacher not only has an understanding of the content but must also have the ability to understand the ability of students to understand the content.

Shulman (1986) identified PCK as one of the most important knowledge bases that teachers must have in order to teach effectively. He stated that having knowledge of the subject matter was not enough to teach it. Teachers also need to have pedagogical content knowledge. This knowledge base, namely PCK, according to Shulman (Koehler et al., 2011)) includes "knowledge and characteristics of learners, knowledge of educational contexts, knowledge of educational goals and values, and their philosophical and historical foundations". Pedagogical Content Knowledge (PCK) represents the intersection between Pedagogical Knowledge (PK) and Content Knowledge (CK), emphasizing that pedagogy and content are inherently interconnected as illustrated in Figure 1. This has led researchers to regard PCK as important as subject-matter knowledge. PCK has become a central concept that has significantly shaped subsequent studies in teacher education (Segall, 2004).

Figure 1.
Pedagogical Content Knowledge (PCK)



Many previous studies examined students' mathematical abilities (according to competence) (Gabriella & Imami, 2021; Nurhalin & Effendi, 2022; Susmawathi et al., 2021), student learning barriers (Maarif et al., 2020; Winarti et al., 2023), student difficulties (Azhimuh et al., 2021; Nuraeniah et al., 2022; Paujiah & Zanthy, 2020), and student errors (Hanipa et al., 2012; Minaldi et al., 2015; Upu et al., 2022) in solving TVLES problems, also analyzing TVLES in mathematics textbooks (Marhami et al., 2024). These studies are oriented towards TVLES learning outcomes. Of course, these results depend on the ability of the teacher's PCK to develop TVLES learning material. Mastery of TPACK is very important for teachers when teaching complex subject matter (Silaban et al., 2024). For this reason, it is necessary to examine the teacher's pedagogical content knowledge abilities in learning TVLES material.

Measuring the ability of PCK needs to be based on several aspects. Aspects of PCK have been assessed by several experts, such as Smith & Neale (1989), Cochran et al. (1993) and Magnusson et al. (1999). This study focuses on the 5 components of PCK teacher abilities described by Magnusson et al. (1999) namely: (1) orientation to teaching, (2) knowledge of the curriculum, (3) knowledge of understanding students' abilities in learning, (4) knowledge of learning strategies for teaching, and (5) knowledge of assessment.

2. Methods

This study examines the PCK skills of mathematics teachers using TVLES material. The type of research used is qualitative research. The subjects of this study were three junior high school mathematics teachers from North Aceh, Southeast Aceh, and Aceh Besar, each with 38 years, 7 years, and 3 years of teaching experience, respectively.

To strengthen data credibility and validity, the study employed three data collection techniques: semi-structured interviews, analysis of the teachers' instructional portfolios, and field notes. The interview protocol consisted of ten questions developed based on the five PCK indicators proposed by Magnusson et al. (1999). All interview sessions were audio-recorded with participants' consent to ensure accurate data capture. In addition, teachers were asked to submit samples of their lesson plans, worksheets, and teaching materials related to TVLES. These portfolios were analyzed to assess the alignment between teachers' stated PCK and their actual instructional practices. Field notes were also taken during and after interviews to document non-verbal cues and contextual nuances not captured in recordings.

The data analysis followed the stages described by Bungin (2003): data collection, data reduction, data presentation, verification, and drawing conclusions. To ensure the trustworthiness of the findings, triangulation was applied in several ways: (1) time triangulation, by conducting interviews at different times to check consistency of responses; (2) method triangulation, by cross-checking interview transcripts, portfolio analysis, and field notes; and (3) data source triangulation, by combining evidence from interviews, teaching portfolios, and observational notes to enhance validity and reliability.

Table 1.

Grid of Teacher PCK Research Instruments

Indicator	Question Grid	Code
Orientation to teaching	Main ideas related to TVLES material delivered to students	A1
	TVLES learning objectives	A2
Knowledge of the curriculum	Knowledge of the TVLES concept but not imparted to students	B1
	The association of elimination methods, substitution and graphical methods in TVLES learning	B2
	Linking TVLES learning with previous material (such as graphical methods with straight line equations, etc.)	B3
Knowledge of students' understanding	Difficulties or limitations related to the TVLES idea/concept	C1
	Factors influencing your learning of the TVLES idea/concept	C2
Knowledge of instructional strategies	Selection of models/methods/approaches in TVLES learning	D1

	Teaching procedures to be used to teach TVLES ideas/concepts	D2
Knowledge of assessment	Specific ways of ensuring student understanding or barriers to TVLES ideas/concepts	E1

3. Result and Discussion

Orientation to teaching

The teacher's ability to identify the main idea or big concept of a material that will be taught/delivered to students is an important thing in learning. Responding to this A1 question, Subject 1 stated that TVLES problem solving methods/strategies such as elimination, substitution, and graphics methods are major concepts learned in TVLES material. Meanwhile, Subject 2 stated that algebraic operations on like terms and mathematical modelling are the basic and main concepts in TVLES material. Subject 3 stated that the main idea in TVLES material is how students can solve problems in everyday life related to TVLES so at the beginning of the meeting, the teacher gives an example of a case involving students regarding TVLES.

The next question (A2) regarding the learning objectives of TVLES, was given to students. Subject 1 said that TVLES learning aims to enable students to be able to solve TVLES problems by using elimination, substitution, combination, and graphic methods. Subject 2 stated that this lesson aims to know TVLES concepts and students are able to connect them with other materials such as geometry and others. Subject 3 stated that with this learning, students were expected to be able to solve TVLES questions using various methods and be able to apply them in everyday life.
The portfolio review shows that Subject 1's lesson plans consistently emphasize multiple solution strategies (elimination, substitution, and graphical methods) while also integrating contextual problems. This strong alignment with interview statements reflects a clear pedagogical focus on both conceptual and procedural understanding. In contrast, Subject 2's instructional materials focus mainly on algebraic methods, with little attention to real-life applications and no inclusion of the graphical method, indicating only partial realization of the intended teaching orientation. Subject 3's documents include some contextual tasks and brief references to the graphical method, but are still dominated by routine, procedural exercises, demonstrating only a limited translation of the teacher's intended real-world connections into practice.

This component of pedagogical content knowledge refers to teachers' knowledge and beliefs about the aims and objectives of teaching at a particular grade level (Magnusson et al., 2006). From the interview results and portfolio analysis above, it was found that although each teacher has different ideas/concepts and goals, if examined more deeply, it is found that the teacher's orientation towards teaching TVLES leads to the same thing, namely the concepts of TVLES and the importance of this being taught to students.

Mathematics should be positioned as an essential and dynamic means for interpreting daily experiences, preparing students for future professions, supporting active and informed participation in society, strengthening critical thinking and problem-solving skills, as well as facilitating the understanding of other academic disciplines (Abbasiana, 2020). In line with this view, the analysis of responses to indicator A2 indicates that all teachers fundamentally aim to provide students with both procedural and conceptual mastery of TVLES, along with the capability to apply these concepts when solving mathematical problems and addressing real-life challenges. Therefore, the primary learning goal consistently emphasized by all subjects is students' ability to comprehend and make effective use of TVLES in various contexts.

Knowledge of the curriculum

There are three research questions related to this second indicator. In question B1, Subject 1 answered that the graphical method material, which was usually taught last, was sometimes left behind or did not have time to be taught because of the time or condition of students who needed a lot of time to understand the previous material. In addition, the teacher still has difficulty teaching students about graphs because the basic concepts of graphs are still lacking, so it takes a lot of time if this method is taught. Subject 2 mentioned that what was not introduced to students was the concept of the graphical method. This is because students find it difficult to understand graphs, so solving TVLES is only taught by algebraic methods such as elimination and substitution. Subject 3 revealed that various solving methods had been taught according to the curriculum, but the questions given were still relatively routine. The teacher has not given non-routine questions that require higher order thinking skills.

The next question (B2) concerns the relationship between the graphical method and the elimination and substitution methods in TVLES learning. Subject 1 explained that attribution was made by giving examples of TVLES cases that have no solution and have many solutions. It was different with Subject 2 which did not associate the graphical method with the others because the concept of the graphical method was not taught to students. Similarly, Subject 3 also does not associate graphical concepts with other methods, even though graphical concepts are still being taught, so that the learning of each method is independent and unrelated to one another. Subject 3 added that the only connection was made by comparing the answers from the elimination method with the substitution method or others.

The last question from this second indicator, namely B3, Subject 1 stated that the association was made by reviewing previous learning, namely the one-variable linear equation, which was the basic concept before the TVLES concept was introduced. In line with that, Subject 2 also relates to the material on one-variable linear equations from the first meeting, such as how to operate the same/similar variables and how to model text questions into equations. Subject 3 also related one-variable linear equations and straight-line equations at the beginning of learning so that TVLES material was easily constructed by students with an existing understanding of their cognitive abilities beforehand.

Regarding curriculum knowledge, Subject 1's lesson plans are well-aligned with official curriculum standards, systematically covering all recommended TVLES methods and featuring a variety of problem types, including those that promote higher-order thinking. Subject 2's portfolio, on the other hand, is focused almost exclusively on algebraic approaches, lacking both the breadth of methods (such as the graphical method) and the inclusion of more complex or contextual tasks, suggesting a narrow interpretation of curriculum requirements. Meanwhile, Subject 3's materials mention some elements of the curriculum but do not implement them comprehensively, with limited depth and inconsistency in applying curriculum components like the graphical method and advanced problem types.

In general, teachers' knowledge of the curriculum is still lacking. The researcher found that in the first two aspects, the graphical method, which is one of the TVLES completion strategies, became a teacher's obstacle in this lesson. From the results of the interviews above, teachers still find it difficult to teach the graphical method, so this method is rarely or even not taught to students at all, so that this has an impact on the connection between other TVLES completion methods/strategies that should be constructed for students.

The graphical method is a strategy for solving TVLES problems by drawing graphs/lines from equations. If you look at the junior high school mathematics textbook for class VIII, this material is studied before other methods. This is done because, with graphics, TVLES interpretation is more visible/representative. Such as constructing the TVLES case, which has no solution can be represented by a graph in the form of two straight lines, and the TVLES case, which has many solutions, can be represented by the graph obtained in the form of one straight line. In addition to their comprehension abilities, students' communication and representation abilities will also increase by learning this strategy. Therefore, the graphical method is an important method to be taught to students in addition to other methods.

Nevertheless, in the last aspect, it appears that the three teachers understand the importance of exploring and connecting students' conceptual concepts with TVLES learning. This activity is useful for finding relationships in the mathematical structure of problems using prior knowledge (Jupri et al., 2014). So it is important for understanding the concept of TVLES.

Knowledge of students' understanding

This third indicator is assessed from two research questions, namely C1 (difficulties or limitations related to the TVLES idea/concept) and C2 (factors influencing TVLES learning). Analysis of the interview data revealed three main categories of student difficulties: (1) graphical method comprehension, (2) procedural understanding of elimination and substitution methods, and (3) foundational algebraic skills including mathematical modeling.

Regarding graphical method difficulties, Subject 1 identified significant challenges in teaching the graphical method, explaining that "*the teacher still has difficulty teaching students about graphs because students still lack the basic concept of graphics*". This finding aligns with Erbaş et al. (2009), who found that students face procedural and conceptual difficulties in solving linear algebraic equations, particularly when visual representations are involved.

Beyond graphical challenges, Subject 1 elaborated on students' conceptual confusion regarding algebraic solution methods: "*Students are sometimes confused about why, when using the elimination method, they have to eliminate one variable. Students still have difficulty at the substitution method stage, they are confused about which equation should be substituted into*". This procedural confusion reflects what Booth and Koedinger (2008) describe as students' misconceptions about algebraic procedures, where learners who begin with misconceptions about the meaning of mathematical symbols solve fewer equations correctly and have difficulty learning correct procedures.

Both Subject 2 and Subject 3 emphasized that students' difficulties stemmed from inadequate foundational skills in algebraic operations. Subject 2 stated: "*Students' basic concepts are lacking in operating like terms. Mathematical modeling is also still difficult for students*". Subject 3 provided additional insight into the extent of this challenge and the pedagogical tension it creates: "*Only 2-3 students truly understand, because one of the difficulties is that students still struggle with algebraic operations such as operating positive and negative numbers. The foundation is still lacking, but because we have to keep up with the material according to the lesson plan, the material is still delivered*". This statement reveals an important tension between curriculum pacing requirements and students' readiness, suggesting that teachers sometimes proceed with content despite recognizing that students lack prerequisite knowledge. Similar findings were reported by Sirkko et al. (2025), who identified 83 unique topic-specific learning difficulties in PCK measures, including procedural and conceptual difficulties in algebra.

Regarding factors influencing TVLES learning (C2), analysis revealed two categories of factors: external factors (facilities and resources) and internal factors (student motivation and attitudes). Two of the three subjects identified inadequate teaching facilities as a significant factor affecting TVLES instruction, particularly for the graphical method. Subject 1 noted: "*Graphics [teaching] lacks facilities*". Subject 3 elaborated on this constraint: "*Factors that influence [learning] include facilities—there is no long ruler, so teachers have difficulty teaching the graphical method. Sometimes students also do not bring rulers, which affects learning with this graphical method*". Despite these limitations, both subjects indicated that instruction continued using alternative available tools.

Subject 2 highlighted internal factors related to student disposition toward mathematics: "*Students' motivation and interest are still lacking toward mathematics material, because of the stigma that learning mathematics is difficult for students*". This finding is consistent with Hossein-Mohand et al. (2023), who found that student motivation appears to be significantly related to perceptions of teaching practices, and students with high motivation have positive perceptions of teaching practices. The stigma surrounding mathematics difficulty reported by Subject 2 reflects what Hodis and Hodis (2022) describe as students' perceptions of cost—when students believe that learning is tiring or frustrating, they struggle in school and become disengaged.

Further analysis of the teachers' portfolios revealed similarities in the approaches used to address student difficulties, namely the use of the scientific approach. However, none of the three lesson plans explicitly included a dedicated section for anticipating potential student difficulties. This finding is significant given Ball et al.'s (2008) emphasis that pedagogical content knowledge includes teachers' understanding of content-related issues around students' learning, such as knowing students' common understanding of certain mathematical concepts and being able to gauge students' understanding based on their responses. All three teachers had prepared worksheets aligned with the intended learning objectives for TVLES material, but most of the tasks consisted of procedural questions without additional support or guidance.

Despite the absence of explicit difficulty anticipation in their planning documents, the interview data demonstrates that all three teachers possess substantive knowledge of students' abilities and the difficulties they encounter in learning TVLES material. This understanding manifests in their adaptive teaching practices. As the teachers indicated, they attempt to minimize difficulties by providing additional guidance in algebraic operations and mathematical modeling to support student learning in TVLES. Sutamrin et al. (2022) states that with PCK teachers are able to understand students' abilities in learning and understand their thoughts. This finding is further supported by Copur-Gencturk and Tolar (2022), who emphasized that pedagogical content knowledge includes teachers' understanding of content-related issues around students' learning. The current study extends this by showing that teachers' knowledge of student understanding exists even when not formally documented in lesson plans, suggesting a gap between teachers' tacit pedagogical knowledge and their formal planning practices. Furthermore, the data reveal that both internal factors (student motivation and mathematical self-efficacy) and external factors (facility limitations) influence TVLES learning. Teachers demonstrate adaptive capacity by continuing instruction using available alternative resources, thereby maintaining student engagement and learning momentum despite material constraints. As noted by Schukajlow et al. (2023), emotions and motivation are important for learning and achievement in mathematics, and teachers who understand these factors can better support student learning.

Knowledge of instructional strategies

The selection of models/methods/approaches in TVLES learning is one of the elements of teacher knowledge in understanding students' abilities in learning. In this case, among Subject 1, Subject 2 and Subject 3 had the same opinion that they more often used lecture and discussion methods in TVLES learning. This is done because, seeing the condition of students who are still difficult to apply models/methods that emphasize student center learning, However, Subject 2 added that, although using the lecture method, sometimes the teacher also applies a problem posing model where students are required to try to compile problems related to everyday life and solve them with a group. Also it was discovered that the use of technology by teachers in teaching TVLES is infrequent, only Subject 3 occasionally used visualizations of linear equations with PowerPoint.

Each subject has its own procedure for teaching the TVLES concept. Subject 1 provides teaching procedures by giving examples of problems that are closely related to students' lives, as well as examples of cases that have no solution but one solution and many solutions to the TVLES problem. Learning the TVLES solving method is carried out directly using the combined method (elimination and substitution), followed by the graphical method. Meanwhile, Subject 2 mentioned that TVLES learning begins with discussing the transformation of text question sentences into mathematical models, followed by studying the methods of elimination, substitution, and combinations. Graphical methods are not taught by teachers. However, students' understanding is strengthened by giving many models of contextual text questions. Subject 3 explained that the main procedure that must be carried out by the teacher in TVLES learning is to review the PLSV concepts such as variables, coefficients, and operations between similar variables, then proceed with learning the graphical method by first being reminded of straight line equations, and then proceed with elimination, substitution, and mixed method.

Analysis of the portfolio documents showed that, although all teachers formally adhered to the scientific approach as required by the curriculum, their practical instructional methods often diverged from this standard. Subject 1's lesson plans consistently included group discussions, but there was no evidence of digital technology use, such as mathematical software, in the portfolio. Subject 2's materials relied predominantly on lectures and simple discussions, lacking exploratory or student-centered activities, which is consistent with the responses given during the interview. Subject 3 occasionally incorporated PowerPoint slides for visualization purposes; however, the majority of instruction still focused on discussion and direct teaching, reflecting limited use of technology and interactive methods. Overall, these findings reinforce the interview results, indicating that a conventional, teacher-centered approach remains prevalent in practice, even though lesson plans formally mention a student-centered scientific approach.

From the analysis of interviews with 3 subjects and documents, it can be concluded that the teacher still uses a conventional approach to TVLES learning even though the lesson plan is written with a scientific approach. In other words, teachers are still stuck in the teacher center learning zone, where this learning model should no longer be used, considering that the current curriculum is based on student center learning. In this case, the teacher is required to be able to increase his creativity in preparing learning scenarios and implementing them in class so that students are able to become active main actors in constructing their knowledge, and learning becomes more interactive and interesting.

The use of technology is also very important in learning. The demands of the times that continue to develop require teachers to be more able to apply technology in learning. However, from the interview results it was found that teachers rarely use technology in TVLES learning. One of the subject's difficulties is using the graphical method where the solution obtained is not an integer. This can be anticipated by applying technology in the form of software applications such as Geogebra. Geogebra has benefits with various activities, such as demonstration and visualization, as a construction aid, and as an aid to the discovery process (Hohenwarter & Fuchs, 2005). Therefore, flexible learning strategies and types of knowledge are needed to successfully integrate the use of technology into teaching (Koehler et al., 2013).

Knowledge of assessment

A specific way of ensuring student understanding or obstacles to TVLES learning is carried out by Subject 1 by giving a question after each presentation of material to test student understanding. Subject 2 gave a test at the end of TVLES learning to students. However, at each meeting, the teacher can find out the extent of the student's understanding by looking at the student's ability to answer the sample questions given. Subject 3 gave practice questions independently in class, with the strategy of questions given not being the same among students. The three subjects said that the practice/repeat questions given were not much different from the examples of questions studied, so the use of non-routine questions was rarely given to students in evaluating student understanding.

From these three answers, it was found that each teacher has a different assessment system. Portfolio analysis revealed that all three teachers predominantly used procedural, routine tasks for assessment, with few or no higher-order thinking questions included. This aligns directly with interview findings, confirming teachers' reliance on procedural assessment methods. Some teachers conducted assessments during the learning process, some after each lesson, and others only at the end of the entire TVLES unit. These choices were closely related to the teachers' understanding of their students' abilities in learning TVLES. Despite these differences in approach, all teachers agreed that assessment is a crucial part of the learning process, as it allows them to determine how well students understand and can solve TVLES problems. As stated by Resbiantoro (2016), effective assessment should include informal, formative, and summative methods to reveal students' understanding of the learning material's concepts.

4. Conclusion

The ability of teachers' PCK towards TVLES learning in this study found that, in general, teachers have abilities in aspects of orientation towards teaching, knowledge of understanding students' abilities in learning, and knowledge of assessment. However, it is still lacking in terms of knowledge about the curriculum and knowledge about learning strategies for teaching. This research is expected to be an input for teachers to continue to improve PCK skills both in TVLES learning and other mathematics learning. Because as long as the breath is still accompanying, learning continues.

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