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Optimizing Transdisciplinary Epistemic Knowledge Through STEAM+X-Integrated Epistemic Learning Patterns in Mathematical Comparison

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ABSTRACT

Low transdisciplinary epistemic knowledge is one of the problems in mathematical comparison learning. Therefore, this study aims to optimize this competency through the development of a teaching module based on epistemic learning patterns integrated with STEAM+X. This study used a design-based research design. The instruments used were a practical problem questionnaire, a transdisciplinary epistemic knowledge test, and a teaching module. The participants were 36 people, consisting of 15 students (aged 13–15 years) and 21 educational stakeholders (teaching experience 0–25 years). Qualitative data were analyzed using thematic analysis, while quantitative data were analyzed using the Wilcoxon Signed Rank Test. The results revealed that identity and orientation crises, lack of spatial experience, pedagogical mismatches, and ecosystem limitations were the contributing factors to low student competency. The learning principles expected to be optimized were student-centered learning, technology integration, and learning ecosystem support. ELP-STEAM+X-AI was then implemented because it aligned with the previous principles. The study concluded that the learning was able to optimize transdisciplinary epistemic knowledge (Z = -2,96; p = 0,003; and r = 0,76 with large impact) because students were facilitated in constructing mathematical comparison concepts through various STEAM+X-based epistemic activities. This finding recommends that other subjects adopt ELP-STEAM+X-AI to optimize student competency.

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1. INTRODUCTION

Mathematics is the queen of sciences [1], [2]. This statement holds profound meaning because mathematics is essentially the foundation of other disciplines. Mathematics plays a significant role in technological development [3], [4]. Mathematics plays a significant role in life [5]. One important mathematical concept frequently encountered in everyday life is comparison [6]. The concept of comparison studied in junior high school includes scale, speed, and equivalent and inverse ratios [7], [8]. The concept of scale is used to facilitate navigation, such as GPS and mapmaking [9], [10]. The concept of speed is used in the automotive and aviation worlds [11]. Meanwhile, the concept of equivalent and inverse ratios is used to estimate the effectiveness and efficiency of a project [12].

Given the importance of the concept of comparison, it is advisable to have good quality learning in the classroom. However, the facts in schools show different results than expected. Several previous studies show that the concept of mathematical comparison tends to be difficult for students to understand [13], [14]. Jablonski [15] reveals that the concept of scale is quite frequently read by students, but tends to be difficult for students to understand in mathematics learning. Khikmiyah et al. [16] reveal that the concept of speed tends to be difficult for students to understand. However, these concepts are quite close to students in their daily lives [17]. Nurgabyl et al. [18], [19] and Testov et al. [18], [19] also reveal that students are not yet able to use various competencies or cross-disciplinary knowledge/transdisciplinary epistemic knowledge (TEK) in solving mathematical problems. In the context of this research, students have been indicated to experience problems in terms of low TEK, especially in the use of comparative concepts and perspectives from various disciplines in solving life problems. In fact, problems in today's era tend to be uncertain and complicated [20], [21]. This condition then shows the gap experienced by students regarding the importance of the concept of comparison, with students' ability to use this concept and various disciplines to solve life problems that tend to be complex.

Quite a lot of research examines how to improve the quality of mathematics learning on the concept of comparison [22], [23], [24], but not many examine it comprehensively, starting from the factors causing low TEK to the development of artificial intelligence (AI)-assisted teaching modules based on epistemic learning patterns (ELP) that integrate STEAM+X (ELP-STEAM+X-AI) to optimize TEK itself. In fact, the existence of AI helps teachers in preparing student-centered learning activities quickly [25], [26], [27], [28]; ELP helps students in constructing knowledge (mathematical concepts) systematically [29], [30], [31]; and the integration of STEAM+X trains students in solving problems by utilizing various knowledge from various disciplinary backgrounds [32], [33]. Therefore, there is a research gap that can be used to optimize TEK through a more comprehensive approach, namely, through ELP-STEAM+X-AI.

ELP is a learning approach that facilitates students building knowledge through systematic learning steps [31]. ELP consists of three main stages in learning, namely epistemic prime, action, and reflection [29]. Epistemic prime includes student orientation activities before constructing knowledge. This activity aims to prepare students before solving problems. Epistemic action is the activity of constructing knowledge by presenting problems for students to solve and formulating mathematical concepts contained in the solution or process of solving the problem. The construction of knowledge is then strengthened by the implementation of these concepts in different problems. In this activity, the integration of STEAM+X is carried out. STEAM+X is a learning approach that combines science, technology, engineering, art, and mathematics in solving problem X (culture, architecture, and history). In this study, the STEAM+X project presented is *Subak Lingsar. Subak Lingsar* is an irrigation system that divides the irrigation of rice fields or fields of Muslim and Hindu farmers in one of the regions in Indonesia. Epistemic reflection is the activity of students in reflecting on the knowledge they have, as well as the social-emotional aspects, after the learning activity ends. This activity aims to evaluate the understanding or achievement of learning objectives during a classroom meeting [30], [31]. Theoretically, several theories underlie this research, namely constructivism, ELP, and STEAM+X, to support students in constructing knowledge, transdisciplinary thinking, and technology-based mathematics learning. In other words, ELP-STEAM+X-AI serves as a comprehensive alternative solution to address the gaps described above.

Based on the previous description, the purpose of this study is to identify the factors causing TEK, formulate learning principles, develop an ELP-STEAM+X-AI module, and test its effectiveness on TEK. This research is expected to provide theoretical and practical contributions to the development of epistemic learning studies and the provision of AI-assisted mathematics learning modules. To achieve this goal, several research questions are derived, including:

1.1. What factors contribute to low student TEK in learning the concept of comparison?
1.2. What learning principles are recommended for optimizing student TEK in learning the concept of comparison?
1.3. What format should an ELP-STEAM+X-AI-based teaching module take to optimize these competencies?
1.4. How is the ELP-STEAM+X-AI-based teaching module implemented in learning the concept of comparison in the classroom?
1.5. What is the effectiveness of the ELP-STEAM+X-AI-based teaching module in terms of TEK?

2. METHOD

The design used in this study was design-based research (DBR). DBR had been chosen because its characteristics had been relevant to the objectives of this study, namely, first identifying the factors causing practical problems, then identifying a learning approach that aligned with the characteristics of these causal factors [34], [35], [36]. This research procedure followed the four steps of DBR: grounding, conjecturing, iterating, and reflecting [32]. In the grounding stage, the researcher conducted focus group discussions (FGDs) with educational stakeholders, such as teachers, principals, and mathematics learning academics, to identify factors contributing to low TEK and alternative solutions to optimize these competencies. Afterward, the researcher conducted a conjecture by developing a teaching module based on ELP-STEAM+X-AI. The module was then reviewed by three experts in mathematics learning and revised according to suggestions from the previous reviewers. Content validity criteria were assessed using *Aiken's V* index, which examined aspects of material, didactics, language, and presentation. The analysis revealed a high *Aiken's V* value of 0.88, representing a high validity criterion. Because the test instrument was in the form of a description with three assessors, reliability estimation was performed using the interclass correlation coefficient (ICC) with two-way random effects and a single measurement (2,1). The analysis yielded an ICC (2,1) of 0,87, which was categorized as good.

The next stage was iterating. After the ELP-STEAM+X-AI-based teaching module was revised based on the results of reviews from several experts, the researcher implemented the teaching module in the classroom. Implementation was carried out in four meetings. Furthermore, at this stage, the researcher tested the effectiveness of the ELP-STEAM+X-AI-based teaching module in terms of TEK. The final stage was reflection. In this stage, the researcher reflected on all previous research activities. A brief summary of the research procedures can be seen in Figure 1.

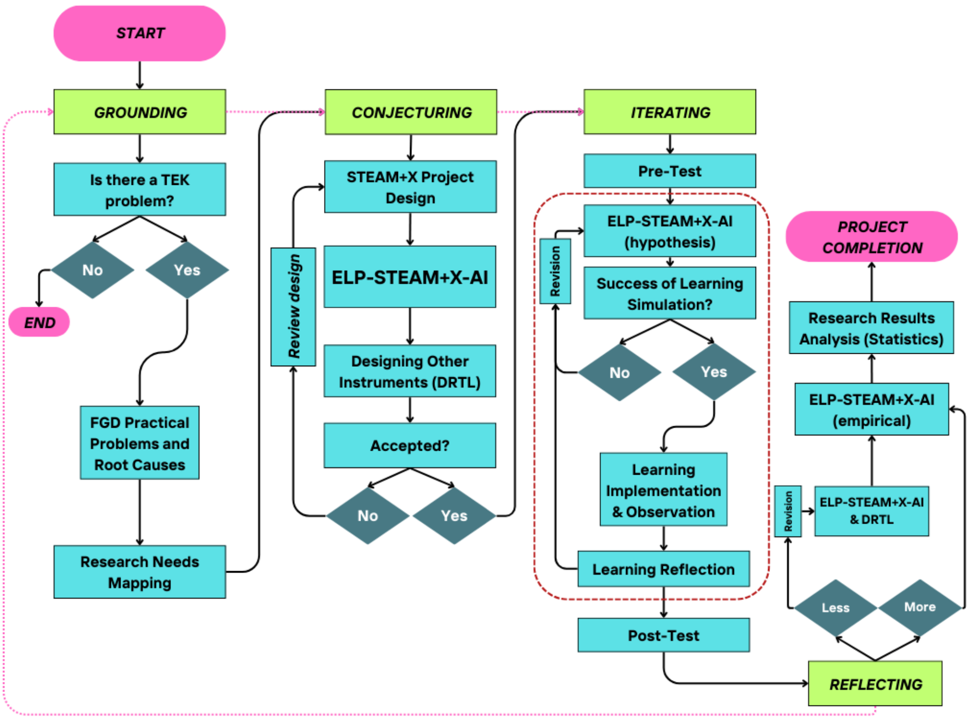

Figure 1. Research procedure

Various instruments were used to collect data at each stage of the research. First, a practical problem questionnaire was used to obtain data related to the existence of low TEK, causal factors, and alternative solutions to optimize this competency. At least six open-ended questions were used in the questionnaire. Second, the ELP-STEAM+X-AI-based teaching module was used to obtain data related to student responses to the learning. Third, a TEK test consisting of five questions was used to measure students' TEK abilities. The test consisted of two types: a pre-test and a post-test. Data triangulation in this study communicated the results of questionnaire analysis, student responses, and test results to optimize the credibility and consistency of the research findings.

The participants in this study were fifteen students who had not yet learned the concept of comparison. The students ranged in age from 13 to 15 years old, with ten females and five males. These participants were selected because they indicated they were experiencing difficulties in learning mathematics from previous mathematical concepts. The number of participants was deemed sufficient for this study because it focused on iteratively developing and refining the learning design, rather than generalizing the results to a population. A smaller number of participants allowed for more in-depth analysis, resulting in richer information. Other participants in this study were twenty-one stakeholders in mathematics learning, consisting of one principal, fourteen teachers, and six mathematics learning academics. The expert participants used in this study were three academics in the fields of education, mathematics, and learning technology with over ten years of teaching experience. This study obtained permission from the school and student consent prior to implementation. All data was kept confidential and used solely for the research context.

The data in this study were analyzed using several analysis techniques according to the data type and research objectives. Data analysis in this study was conducted in stages, beginning with thematic analysis to analyze qualitative data, followed by inferential statistical analysis to examine quantitative data related to learning impact. Thematic analysis was used to analyze the data from the practical problems questionnaire. The stages of the thematic analysis followed several activities: familiarizing oneself with the data, determining initial codes, identifying themes, reviewing themes, and defining themes [37], [38]. Inferential statistical analysis was performed using the Wilcoxon Signed Rank Test because the data were not normally distributed and the number of participants was relatively small [39].

3. RESULTS AND DISCUSSION

3.1. Results

Thematic Findings

The results of the thematic analysis revealed five themes related to factors contributing to students' low TEK competency and three themes related to alternative solutions to optimize this competency. A summary of the analysis results can be seen in Table 1.

Table 1. Thematic analysis results

Causal Factors Theme	Description	Alternative Solutions Theme	Description
A crisis of identity and orientation	Students' tendency to lose direction and lack an identity as active learners.	A student-centered approach	A student-centered spatial learning approach combined with a holistic approach.
A lack of spatial experience	A lack of exposure and practice in three-dimensional (3D) contexts.	Technology and innovation.	Technology-based multimodal learning for 3D contexts.
A crisis of motivation and engagement	Reduced student interest and active involvement in the learning process.	Ecosystem support	The need for a learning ecosystem.
Pedagogical mismatch	Incongruence of the teaching methods.		
A limited ecosystem	A lack of systemic support.		

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ELP-STEAM+X-AI Based Learning Module

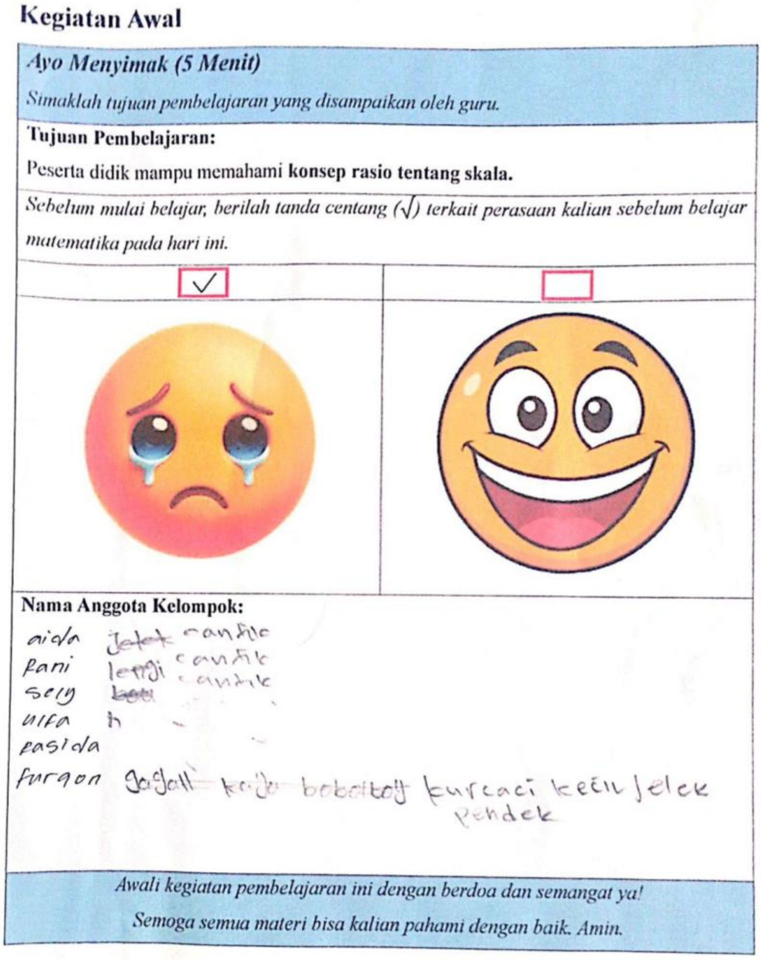
Referring to the three principles above, one learning approach was guided by these principles. This learning approach was ELP. In the context of this research, ELP did not stand alone but was integrated into multimodal learning, such as STEAM+X. More operationally, this research used an ELP-STEAM+X-AI-based learning module to optimize TEK. The module consisted of three main activities: epistemic prime, epistemic action, and epistemic reflection. In the epistemic prime, students were oriented to the learning objectives, were provided with motivational stories that stimulated learning motivation, and were prepared with prerequisite materials used to solve problems. In epistemic action, students are given the opportunity to solve problems in groups. The problems presented in this context are STEAM+X problems. In this research context, the researcher used *Subak Lingsar* as the basis for each problem solved by students.

After solving the problem, student representatives from each group were asked to present their solutions and processes to the class. Students were then asked to comment on each other and provide suggestions based on the presentations of their previous groups. Afterward, students in the ELP-STEAM+X-AI-based learning module were facilitated to summarize the solutions and comparative concepts contained in the problem being solved. The next activity asked students to solve another STEAM+X-based problem using the concept of comparison they had learned. The final activity in the learning module was epistemic reflection. In this activity, students were asked to reflect on the concept of comparison they had learned. Furthermore, the learning module also facilitated students' reflection on their feelings after the lesson.

Implementation of ELP-STEAM+X-AI Based Learning Module

The ELP-STEAM+X-AI-based learning module had then been implemented in four iterations. The following was a description of one of the learning sessions. In the initial learning activity, students were asked to prepare their writing materials as usual. Afterward, the model teacher distributed the previously prepared learning module to be worked on in groups. In the initial learning activity, students were asked to pay attention to and/or review the learning objectives contained in the module. In this session, the mathematics learning objectives were related to the concept of scale.

The next activity involved students expressing their feelings before beginning the learning activity. In this activity, most students expressed feelings of sadness at the time. A sample of student responses could be seen in Figure 2. The following activity involved reading a motivational story. In this activity, students read a story related to the benefits of the concept of scale in everyday life. One student was asked to read the story, and the other students were asked to provide responses regarding the message conveyed in the story. In this activity, students were able to explain that scales were commonly used when reading maps and planning trips.


Kegiatan Awal

Ayo Menyimak (5 Menit)

Simaklah tujuan pembelajaran yang disampaikan oleh guru.

Tujuan Pembelajaran:

Peserta didik mampu memahami **konsep rasio tentang skala.**

Sebelum mulai belajar, berilah tanda centang (√) terkait perasaan kalian sebelum belajar matematika pada hari ini.

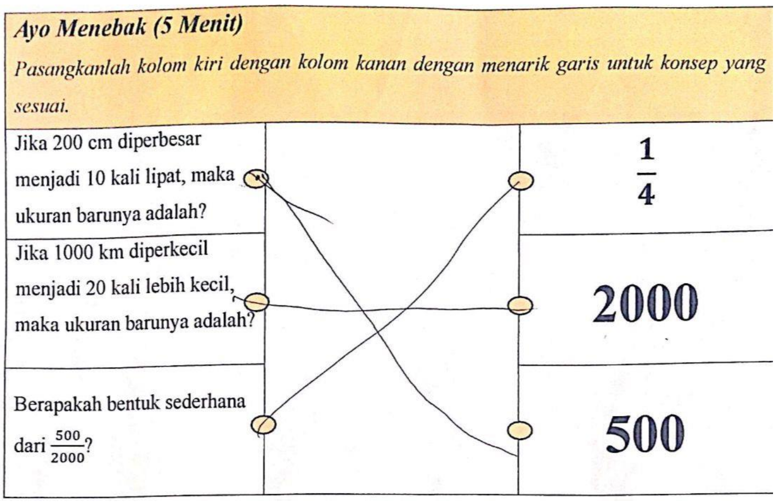
Nama Anggota Kelompok:

aida ~~jelek~~ cantik
rani tinggi cantik
sely cantik
ulfa
rasida
furqon

Awali kegiatan pembelajaran ini dengan berdoa dan semangat ya!
Semoga semua materi bisa kalian pahami dengan baik. Amin.

Figure 2. Excerpts from students' reflection answers on feelings before learning

Afterward, students were asked to guess several prerequisite concepts related to scale. In this activity, students were asked to simplify fractions and determine the size of an object when enlarged or reduced. A sampling of student responses could be seen in Figure 3.


Ayo Menebak (5 Menit)

Pasangkanlah kolom kiri dengan kolom kanan dengan menarik garis untuk konsep yang sesuai.

Jika 200 cm diperbesar menjadi 10 kali lipat, maka ukuran barunya adalah?	$\frac{1}{4}$
Jika 1000 km diperkecil menjadi 20 kali lebih kecil, maka ukuran barunya adalah?	2000
Berapakah bentuk sederhana dari $\frac{500}{2000}$?	500

Figure 3. Excerpts from students' answers to the activity of guessing prerequisite material

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After completing the prerequisite material, students were asked to solve a problem related to STEAM+X, namely Subak Lingsar. In this problem, students were asked to sketch a rice field area using the desired scale. Students were also given assistance using *Google Gemini* to find ideas related to the rice fields they created. Excerpts from student answers could be seen in Figure 4.

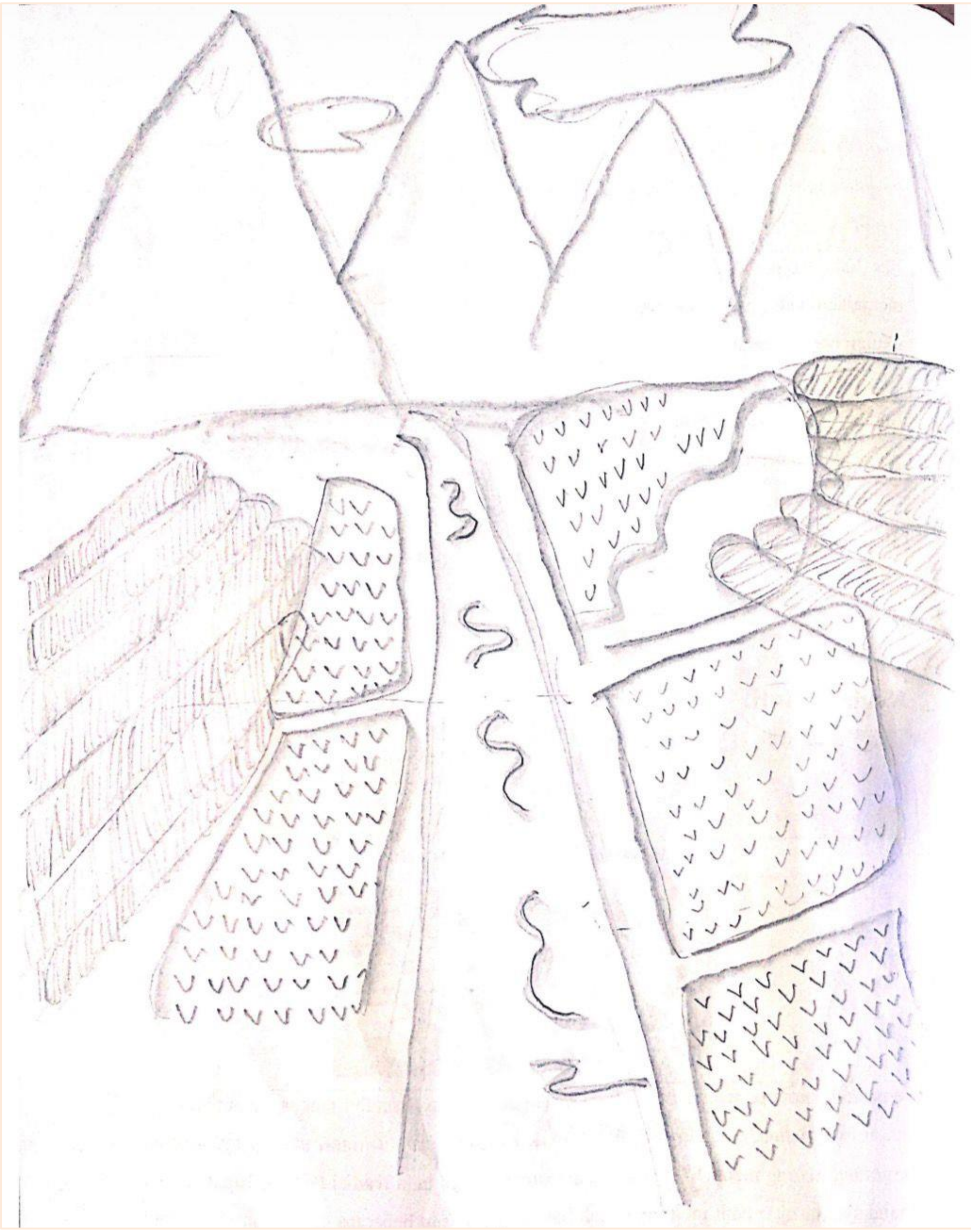
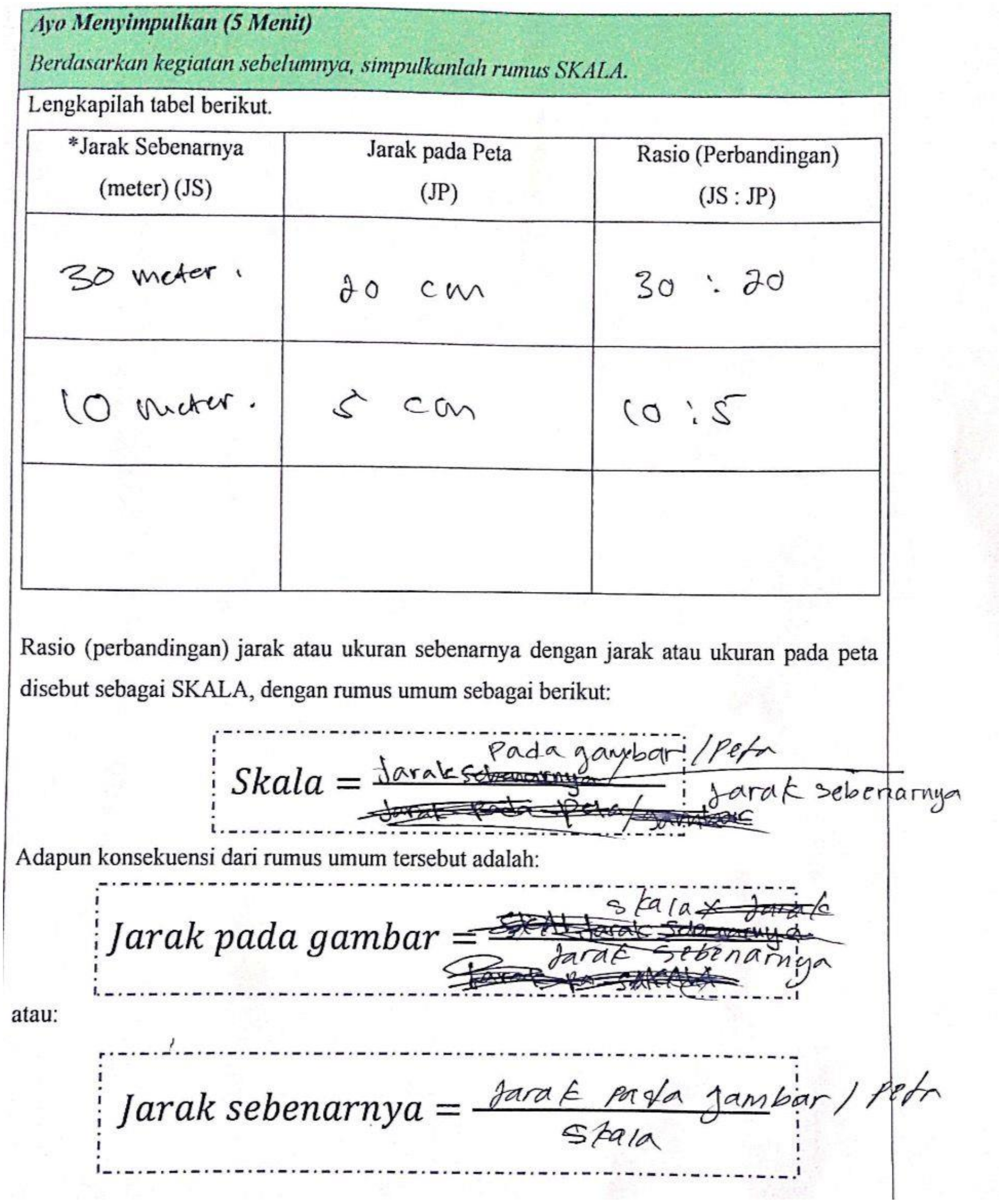


Figure 4. Excerpts of students' answers when solving problems

Representatives from each group were then asked to present their solutions to the class. Other students were asked to provide comments or questions to the group presenting. During this activity, students appeared to be suboptimal, particularly when responding to the students presenting. The next activity involved students deducing the general formula for the scale based on the activities they had undertaken. Because students were suboptimal in solving the problems, they tended to be unable to draw conclusions during this activity. With the teacher's assistance, students were then able to deduce the general formula for the scale. A snapshot of student responses to this activity could be seen in Figure 5.



Ayo Menyimpulkan (5 Menit)

Berdasarkan kegiatan sebelumnya, simpulkanlah rumus SKALA.

Lengkapilah tabel berikut.

*Jarak Sebenarnya (meter) (JS)	Jarak pada Peta (JP)	Rasio (Perbandingan) (JS : JP)
30 meter.	20 cm	30 : 20
10 meter.	5 cm	10 : 5

Rasio (perbandingan) jarak atau ukuran sebenarnya dengan jarak atau ukuran pada peta disebut sebagai SKALA, dengan rumus umum sebagai berikut:

$$Skala = \frac{\text{Pada gambar / Peta}}{\text{Jarak sebenarnya}}$$

Adapun konsekuensi dari rumus umum tersebut adalah:

$$Jarak\ pada\ gambar = \text{skala} \times \text{Jarak sebenarnya}$$

atau:

$$Jarak\ sebenarnya = \frac{\text{Jarak pada gambar / Peta}}{\text{Skala}}$$

Figure 5. Excerpts of students' answers when solving problems

Due to the considerable time required, the *"Let's Practice"* activity could not be completed independently by students in this meeting. Students completed the activity together with the teacher in front of the class. The activity continued with a final activity, where students were asked to reflect on the concept of scale. In this activity, students were able to correctly reflect on the general formula for scale, but they still felt sad after the learning activity. A snippet of student responses could be seen in Figure 6. Although in the first meeting the learning was not optimal in terms of the process aspect, students were seen to have experienced increased activity in the following meetings.

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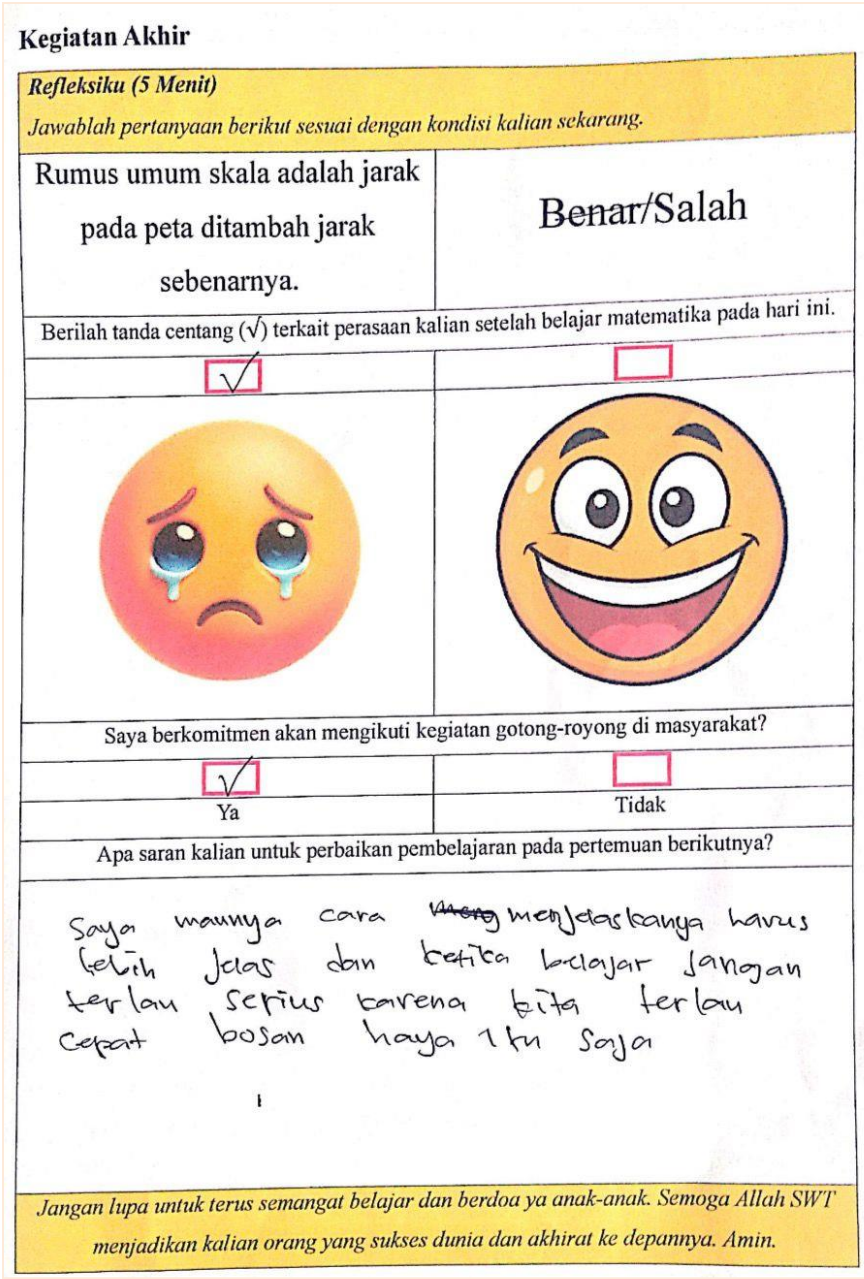
Kegiatan Akhir

Refleksiku (5 Menit)

Jawablah pertanyaan berikut sesuai dengan kondisi kalian sekarang.

Rumus umum skala adalah jarak pada peta ditambah jarak sebenarnya.	~~Benar~~/Salah

Berilah tanda centang (√) terkait perasaan kalian setelah belajar matematika pada hari ini.

√	

Saya berkomitmen akan mengikuti kegiatan gotong-royong di masyarakat?

√	
Ya	Tidak

Apa saran kalian untuk perbaikan pembelajaran pada pertemuan berikutnya?

Saya maunya cara ~~meng~~ menjelaskanya harus lebih Jelas dan ketika belajar Jangan terlau serius karena kita terlau cepat bosan haya itu Saya

Jangan lupa untuk terus semangat belajar dan berdoa ya anak-anak. Semoga Allah SWT menjadikan kalian orang yang sukses dunia dan akhirat ke depannya. Amin.

Figure 6. Excerpts from students’ answers during reflection activities after learning

In summary, student responses in learning for the four meetings could be seen in Figure 7. Figure 7 showed that there had been an increase in student responses for each component of the module activity, both for epistemic prime, epistemic action, and epistemic reflection.

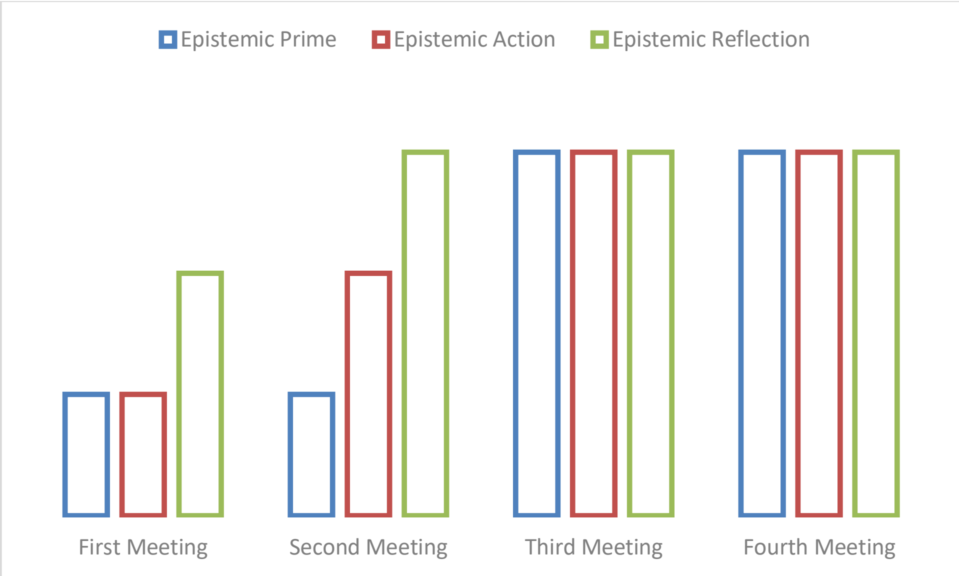

Figure 7. Student responses at each meeting

Effectiveness of ELP-STEAM+X-AI Based Learning Module

Descriptively, most students experienced an increase in scores from the pre-test to the post-test. However, it was found that one student experienced a decrease in their post-test score. Statistik deskriptif bisa dilihat pada Table 2. In summary, the comparison of students' pre-test and post-test scores can be seen in Figure 8. Because the data were not normally distributed, the analysis used to test the effectiveness of the ELP-STEAM+X-AI-based teaching module was the *Wilcoxon Signed Rank Test*. The analysis had indicated a significant difference between the pre-test and post-test scores with Z = -2.96; p = 0,003; and r = 0,76.

Table 2. Statistik deskriptif

Variabel	Count	Mean	Standard Deviation	Minimal	Median	Maximal
Pre-test	15	38,67	36,84	0	44	92
Post-test	15	40,80	40,18	0	34	96

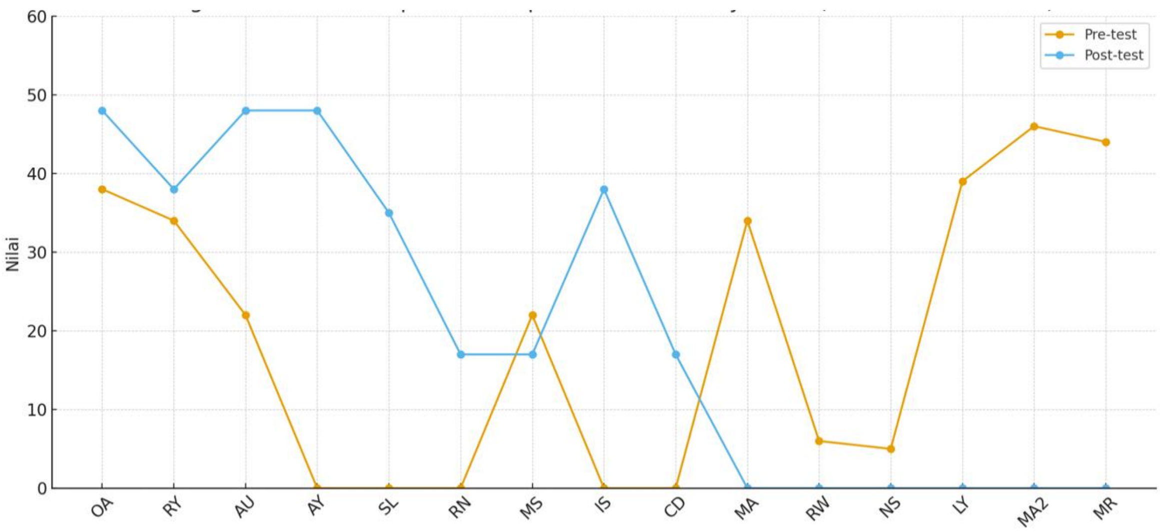

Figure 8. Comparison of pre-test and post-test scores

3.2. Discussion

The research reveals that students' low TEK is likely due to their prior mathematics instruction. The mathematics instruction provided by teachers tends to emphasize procedural aspects rather than exploration of spatial experiences and manipulative activities with geometric objects. These findings align with Kunhertanti et al. [40], which reveals that students tend to lack confidence in being good or active learners during mathematics learning. Students tend to feel they will passively participate in learning, thus lacking confidence in their ability to succeed in mathematics [41]. Özçakır et al. [42] also reveal that mathematics learning tends to under-facilitate students' use of three-dimensional thinking skills. Learning tends not to present three-dimensional shapes that can be manipulated or modified during mathematics learning [43], [44].

Previous mathematics instruction likely results in low student motivation. This is because students lack a grasp of the benefits of the mathematical concepts they are learning, resulting in a lack of student engagement in the learning process. Antoniou et al. [45] further support these findings by revealing that students tend to lack motivation when learning mathematics. Numerous factors contribute to low student motivation in mathematics learning, such as perceived irrelevant mathematical concepts to everyday life [46] and teachers' unengaging teaching methods [47]. Several previous studies also reveal that the learning approaches used by teachers in mathematics learning tend to be less engaging for students [48], [49]. The learning methods used by teachers tend to be less suited to student characteristics, causing students to feel that mathematics is too abstract to understand [50]. The lack of facilities to support students in learning three-dimensional concepts is a contributing factor to low TEK. The results of this study align with Tachie [51], which reveals that mathematics learning is sometimes problematic due to the limited tools or learning media used by teachers or owned by schools. Teachers' lack of skills in using various three-dimensional learning technologies is another factor related to the results of this study [52].

Addressing these causal factors, the results also reveal four learning principles expected to optimize TEK. First, a student-centered learning approach. These results align with several previous studies [31], [53], which recommend the use of student-oriented learning, providing opportunities for students to solve problems, and facilitating students to engage in hands-on activities during mathematics learning. This is because student-centered learning has a positive effect on students' cognitive development [29], [30]. In fact, students who participate in student-centered learning are more active during learning activities [54].

The integration of technology and learning innovation is likely to impact the optimization of TEK. This is because technology enables more interactive and concrete spatial visualizations for students. AI support and the presence of multimodal activities are then expected to provide a medium for students to explore three-dimensional concepts with greater flexibility than through direct learning. The results of this study are in line with Dockendorff [55], which reveals that the use of technology related to mathematical concepts is a recommendation to optimize students' mathematical competence. Azevedo et al. [56] also reveal that innovation in mathematics learning is necessary to optimize students' mathematical competence. Innovation makes students more interested in learning mathematics, so they are more focused during learning, and this automatically has an impact on students' cognitive abilities [57]. Third, support for the mathematics learning ecosystem is a principle that must be emphasized to optimize the quality of mathematics learning. The results of this study are in line with Nguyen et al. [58], which reveal that ecosystem support has a positive effect on the quality of mathematics learning in schools. For example, the existence of interactive learning media helps students to explore mathematical concepts better [59].

Based on the previous learning principles, this study implements ELP-STEAM+X-AI because it meets the criteria for all of these principles. This learning implementation is also based on several previous studies [30], [31], [53], which reveal that ELP implementation has a positive impact on the development of problem-solving skills, representation skills, and students' motivation for learning mathematics. This is because a series of activities in ELP facilitates students' conceptual construction through various student-centered activities [29]. The results of this study also align with several previous studies that reveal that STEAM+X has an impact on improving the quality of learning, both in terms of student and teacher competency [32].

During the learning implementation, the ELP-STEAM+X-AI activities begin with an epistemic prime, which relates to orientation activities for students before they construct knowledge. These results align with previous research by Isnawan et al. [29], which reveals that orientation activities are the initial activities students must undertake during learning. In the epistemic prime activity, students are asked to read the learning objectives contained in the module. This is intended to help students understand the target knowledge or mathematical concepts they must master at that meeting. By understanding the learning objectives, mathematics learning is more focused and measurable [60]. Before reading the motivational story, students are asked to express their feelings before the lesson begins. This activity aims to determine students' social-emotional state at the beginning of the lesson and can be used as an indicator of learning success at the end [61].

Afterward, students read the motivational story during the implementation and then convey the message contained in the story. For example, research results reveal that students express that the concept of scale has various benefits in everyday life. The presence of a motivational story that emphasizes the importance of mathematical concepts is expected to motivate and increase students' enthusiasm for learning because they understand the benefits of the concept for their future [62]. Next, students answer several prerequisite questions, and they are able to answer them well. This indicates that they are cognitively ready to learn. Cognitive readiness before learning is a crucial aspect of mathematics learning [63], especially at the beginning of the session.

The next activity involves students solving problems. Unfortunately, in this activity, students are not yet optimally able to solve the problems. Students tend to be unable to sketch rice fields precisely. This obstacle likely indicates that students are unfamiliar with open-ended problems and visual representation activities in real-world contexts. Previous mathematics instruction may focus on routine problems, making it difficult for students to construct solutions to these non-routine problems independently. This is because they do not yet understand the instructions well enough. The results of this study are in line with Moleko

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et al. [64], which reveals that one of the obstacles when students solve problems is their ability to understand the instructions in the problem or understand the mathematical problem itself. Students' low literacy skills in understanding questions are one of the factors causing these obstacles [65]. Students also tend not to be optimal in dividing tasks when solving problems. Cooperation between students tends not to run well. The results of this study are in line with Chen [66], which reveals that students tend to be less able to coordinate with colleagues when solving problems.

After solving the problem, students present their solutions and the processes they undertake. Representatives from each group present their work, but no students volunteer. The teacher appoints one group to present. The other students have not yet respond to the previous student's presentation. This low response rate is likely due to the previous teacher-centered learning culture. This, in turn, results in passive student learning, making it difficult for them to express their opinions. The results of this study align with Alfaiz et al. [67], which reveal that students tend not to volunteer to present assignments in mathematics lessons. This is because students are not yet accustomed to presenting because previous mathematics lessons provide little opportunity for students to facilitate [68], [69].

The teacher assists students in formulating the general scale formula because students are not yet proficient in solving problems. The results of this study align with Sridana et al. [53], which reveal that students tend not to be able to discover concepts independently but instead need assistance from peers or teachers. This aligns with social constructivist theory, which states that students tend to be able to solve problems when there are colleagues or peers who are more capable of helping [29]. The findings of this study also support the social constructivist perspective, especially aspects related to scaffolding collaboration in order to support students when carrying out spatial reasoning. In the context of the theory of didactic situations, this contract is referred to as a *maieutic Socratic contract* [31], [70]. The same applies to answering practice questions. Students work together with the teacher to solve problems. This activity aims to strengthen student understanding. The results of this study align with Bego et al. [71], which states that practice questions are given to students to optimize their understanding of newly learned mathematical concepts.

The final activity is reflection. Students perform well during this activity. All activities proceed smoothly. During the concept reflection, students are able to correctly determine the general formula for the scale. This mathematical concept reflection activity aims to reconfirm whether the learning objectives have been achieved [72]. The results of this study align with Menekse [73], who states that students are able to effectively reflect on mathematical concepts when implementing student-centered learning. This is because students construct their own mathematical concepts [74]. Finally, students still feel sad at the end of the learning session. In other words, learning does not optimally impact students' social-emotional well-being. These findings indicate that students may require longer emotional adaptation than cognitive adaptation. Students may feel uncomfortable and unaccustomed to new learning activities.

Overall, there is an increase in student engagement from meeting to meeting. This is evident in the last two meetings, where students are able to successfully complete almost all activities. This is because students have become accustomed to the learning activities. In fact, all students at the final meeting feel happy after the learning activities. This increase in student activity shows that adaptation time is one of the keys to the success of innovative learning. The results of this study align with Han [75], which reveals that students tend to be passive during the initial sessions of innovative learning and become more active after becoming accustomed to the learning activities.

This improved activity subsequently impacts the development of students' TEK. The results of this study reveal that the ELP-STEAM+X-AI-based learning module significantly optimizes TEK. This is because students are given the freedom to construct concepts about comparison, such as scale, while working on the module. In fact, in ELP-STEAM+X-AI, students are actively involved from the beginning of the learning activity to the end. These results align with those of Isnawan et al. [29], which reveal that ELP can optimize students' problem-solving abilities. This is because students are given more in-depth opportunities to construct the mathematical knowledge or concepts they are learning. Several previous studies also reveal that ELP can optimize students' mathematical representation skills and learning motivation [30], [31], [53]. Several previous studies also reveal that STEAM+X-integrated mathematics learning can improve the quality of learning in mathematics classes [32], [76], [77].

The effectiveness of ELP-STEAM+X-AI is likely due to the integration of various activities simultaneously, such as learning that tends to be epistemic and contextual and involves multimodal exploration during learning. The integration of these aspects is likely to help students construct mathematical knowledge through collaborative discussions, direct experiences during learning, and ongoing conceptual reflection. These activities are likely to strengthen students' understanding, especially in connecting mathematical concepts with everyday life contexts. This finding then strengthens and expands the theory of epistemic learning. This is because the integration of multimodal activities based on STEAM+X-AI not only focuses on supporting the construction of mathematical knowledge but also strengthens student engagement in mathematics learning. In short, ELP helps students construct concepts, STEAM+X increases student activeness in learning, and AI helps students explore ideas.

However, there is one non-didactic factor that is also assumed to increase student activity during learning. This activity is giving food rewards to active students. The existence of these rewards makes students more open to the model teacher and motivates them to provide a quick response after learning. The results of this study are in line with several previous studies, which reveal that giving rewards during learning makes students more active and happy with the teacher [78], [79]. This is in line with the theory that states that learning motivation is directly proportional to students' mathematics achievement [80], [81]. In this context, rewards likely increase student engagement in learning. However, consistently providing rewards is probably inappropriate, as it tends to make students dependent on external motivation in learning and results in a lack of intrinsic motivation. For example, students are concerned that they do not respond optimally to learning when there are no rewards from the teacher.

4. CONCLUSION

The findings of this study indicate that ELP-STEAM+X-AI is effective in optimizing students' TEK because its learning is student-centered and integrates relevant technology. These findings then imply that the integration of ELP, STEAM+X, and the use of AI in producing teaching modules can be a potentially effective framework in optimizing students' mathematical competence. However, this study has limitations, particularly in terms of the use of a relatively small sample, implementation limited to only one school, and the relatively short duration of implementation. Therefore, future research is expected to use a larger sample, implementation in several schools, and a longer duration of implementation. In addition, the use of more diverse cultural contexts, as well as an in-depth study of the role of food rewards and AI integration, can be other follow-up research areas. Practically, this study then contributes to the provision of innovative learning modules that have the potential to assist teachers, especially in the implementation of technology-based transdisciplinary learning.

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