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Hypothetical learning trajectory trigonometry based on problem-based learning with Jambi malay ethnomathematics nuances

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Abstract

Background: Trigonometry is a challenging subject for many high school students. Incorporating cultural relevance, such as Jambi Malay ethnomathematics, into teaching can be a way to facilitate understanding. This study focuses on developing a hypothetical learning trajectory (HLT) tailored to Class X high school students on the topic of trigonometry.
Aim: The primary goal of this research is to create a valid, practical, and effective HLT for trigonometry based on problem-based learning, integrating the nuances of Jambi Malay culture.
Method: This study employed a combination of two design research models: the Plomp model and the Gravemeijer and Cobb model. The research was conducted in three stages: 1) initial investigation, 2) product development, and 3) assessment. Expert validation and practical testing were carried out to assess the quality of the HLT.
Result: Validation by experts indicated that the developed HLT achieved a score of 3.69, falling into the "very valid" category. Practicality testing revealed a score of 80.14, categorizing it as practical. Moreover, the HLT proved effective in enhancing students' mathematical communication skills.
Conclusion: The developed Trigonometry HLT based on problem-based learning and integrated with Jambi Malay ethnomathematics is valid, practical, and effective. It not only adheres to quality benchmarks but also significantly improves students' mathematical communication abilities. Therefore, it fulfills the criteria for being a suitable and effective teaching approach.

INTRODUCTION

Trigonometry, an essential mathematical discipline, is commonly introduced to students in the 10th grade. This subject encompasses various aspects, including the study of trigonometric ratios in right-angled triangles, angle relationships, identities in trigonometry, as well as the sine and cosine laws, besides exploring trigonometric functions. Its practical applications are significant in fields such as architecture, navigation, and engineering, along with certain areas of physics, making it a crucial tool for precise measurements of lengths and angles (Subroto & Sholihah, 2018). Despite its importance, a notable challenge has been observed in students' proficiency in tackling trigonometric problems. As noted by Aminudin et al. (2019), a substantial number of high schoolers find trigonometry to be one of the more challenging segments in their math curriculum. Research by Shofiah et al. (2018) attributes this difficulty to the extensive use of complex formulas and the abstract nature of the subject, which students

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often find hard to grasp. Additionally, a lack of real-life contextualization in teaching methodologies contributes to students' disinterest, adversely impacting their academic performance in this area. An effective strategy to enhance students' grasp of trigonometry is the implementation of the Problem Based Learning (PBL) approach. Siagian et al. (2019) describe PBL as a method that involves presenting students with real-world, meaningful problems, thereby facilitating better engagement, and understanding. This approach not only encourages students to thoroughly analyze and critique problems but also significantly boosts their motivation to find solutions.

Trigonometry extensively employs various symbols, serving as a vital tool for mathematical expression. According to Permendikbud Number 22 of 2016, a primary objective in mathematics education is to effectively convey ideas or reasoning using methods like diagrams, tables, symbols, and other forms of media, to simplify and elucidate complex problems. A study by Rismen et al. (2020) revealed that the mathematical communication abilities of tenth-grade MIA students at SMAN 1 Koto Salak predominantly fell into the less favorable category.

Further, a trigonometry-based mathematical communication assessment conducted with eleventh grade MIPA students at SMA Adhyaksa 1 Jambi uncovered a significant gap in problem-solving abilities related to trigonometry, particularly in the sine rule subtopic. A common error observed was the students' inability to depict the known sides and angles of a problem accurately and comprehensively through illustrative means. The ability to graphically represent elements of a contextual problem stands as a crucial aspect of mathematical communication. Addressing this issue is imperative, as visual representation plays an essential role in enhancing students' competency in mathematical communication.

The approach to teaching trigonometry remains largely ineffective. Teachers often serve as the primary source of information, which leads to a limited variety of instructional resources. This situation hinders students' ability to grasp the subject thoroughly (Rahmawati et al., 2019). A similar observation was made during an interview with a math teacher at SMA Adhyaksa 1 Jambi. The teacher relied on standard trigonometry materials, which were not effectively utilized to guide students in exploring key trigonometric concepts such as ratios, sine and cosine rules, and the calculation of triangle areas using trigonometry. Moreover, the instruction provided fails to connect trigonometry to students' real-world experiences or integrate it with cultural aspects. To create a learning environment that resonates more with students' everyday experiences, incorporating cultural elements into mathematics education is beneficial. This approach, known as Ethnomathematics, not only enriches learning but is also aligned with the goals set forth in Law no. 5 of 2017, which advocates for cultural advancement through educational practices.

In the realm of this study, various research efforts have been undertaken, revealing that employing the Problem-Based Learning (PBL) approach significantly enhances students' mathematical competencies. This includes bolstering communication skills, as noted by Putri et al. (2021), and augmenting problem-solving capabilities, a finding supported by the works of Armiati et al., 2018; Julita, 2018; Siagian et al., 2019; Oktaviana & Suparman, 2020. Additionally, Khoirudin & Rizkianto (2018) observed an improvement in reasoning abilities, while Meriyati et al. (2018) confirmed enhanced overall learning outcomes. An alternative strategy to foster mathematical abilities and learning results is through learning experiences imbued with ethnomathematics.

The adoption of ethnomathematics in mathematical education has been explored by several researchers before. They discovered that integrating cultural elements into mathematics education positively influences various aspects of students' mathematical skills. This includes problem-solving skills as highlighted by Simamora et al. (2019), mathematical communication abilities as per Muhammad et al. (2023), alongside critical (Ainin et al., 2020) and creative thinking skills (Ramadhani et al., 2020), and the development of mathematical logical intelligence (F.A et al., 2021). Moreover, merging Problem-Based Learning with ethnomathematical elements in mathematical instruction has also been demonstrated to bolster student learning outcomes, as evidenced in studies by Safitri et al. (2020) and Maidiyah et al. (2021).

This study is dedicated to developing a credible Hypothetical Learning Trajectory (HLT) in the field of trigonometry. Prior studies (Nupus et al., 2022; Armiati & Hidayati, 2023) have established trigonometry HLTs, demonstrating significant enhancements in classroom learning. The implementation of HLTs in mathematics teaching has yielded numerous benefits, aiding students' comprehension of mathematical concepts (Khoirudin & Rizkianto, 2018; Astuti & Wijaya, 2021; Wijaya et al., 2021; Carballo et al., 2022). It is crucial to address these educational challenges promptly to prevent future difficulties for students, particularly those aspiring to pursue higher education. A viable approach is the creation of an effective HLT for an impactful teaching experience.

Therefore, this study proposes a PBL-based trigonometry HLT, integrating cultural elements. Research by Nupus et al., (2022) indicates that incorporating PBL into trigonometry teaching strategies is beneficial. Additionally, ethnomathematics-oriented teaching has been shown to enhance student capabilities, including mathematical communication skills (Muhammad et al., 2023). No existing research bridges Jambi Malay culture with PBL in the context of trigonometry. This study aims to develop a PBL-influenced trigonometry HLT, enriched with Jambi Malay ethnomathematics, striving to create a valid, practical, and effective educational tool.

METHODS

Design:

This study is focused on developmental research with the objective of creating a trigonometry Hypothetical Learning Trajectory (HLT) centered on the sine rules. This HLT is designed with an ethno-mathematics perspective infused with Problem-Based Learning (PBL) to enhance mathematical communication abilities. The research methodology integrates elements from two distinct design research models: the Plomp model (Plomp & Nieveen, 2013) and the Gravemeijer and Cobb model (Akker et al., 2013). This approach encompasses three critical phases: initial research, development, and evaluation. The detailed research procedure planned for this study is depicted in Figure 1.

Participants:

In this article, the pre-designed HLT is validated by experts. Aspects assessed by the validator include aspects of content and language aspects. After the HLT was declared valid, it was followed by a product trial by 6 students, which were divided into two high-ability students, 2 medium-ability students and 2 low-ability students.

Instruments:

The validity of the product is seen by using a validation sheet that has been validated beforehand by 2 mathematician lecturers and 1 linguist lecturer. Next, the six students were given a questionnaire to see product practicality and a mathematical communication test to see product effectiveness.

Data Analysis:

In this study, the average score of the validation assessment score by the validator was guided by the validity criteria put forward by Ardila which can be seen in Table 1 (Ardila et al., 2021).

Table 1. Learning Design Validity Criteria

Average	Criteria
$3{,}50 \leq R \leq 4{,}00$	Very Valid
$3{,}00 \leq R \leq 3{,}49$	Valid
$2{,}00 \leq R \leq 2{,}99$	Less Valid
$1{,}00 \leq R \leq 1{,}99$	Invalid

Based on the validity criteria above, it can be seen that the PBL-based learning design with Jambi Malay ethnomathematics nuances that has been designed in this study can be said to be valid if it meets the criteria with an average of ≥ 3.00, namely the design is in the valid category.

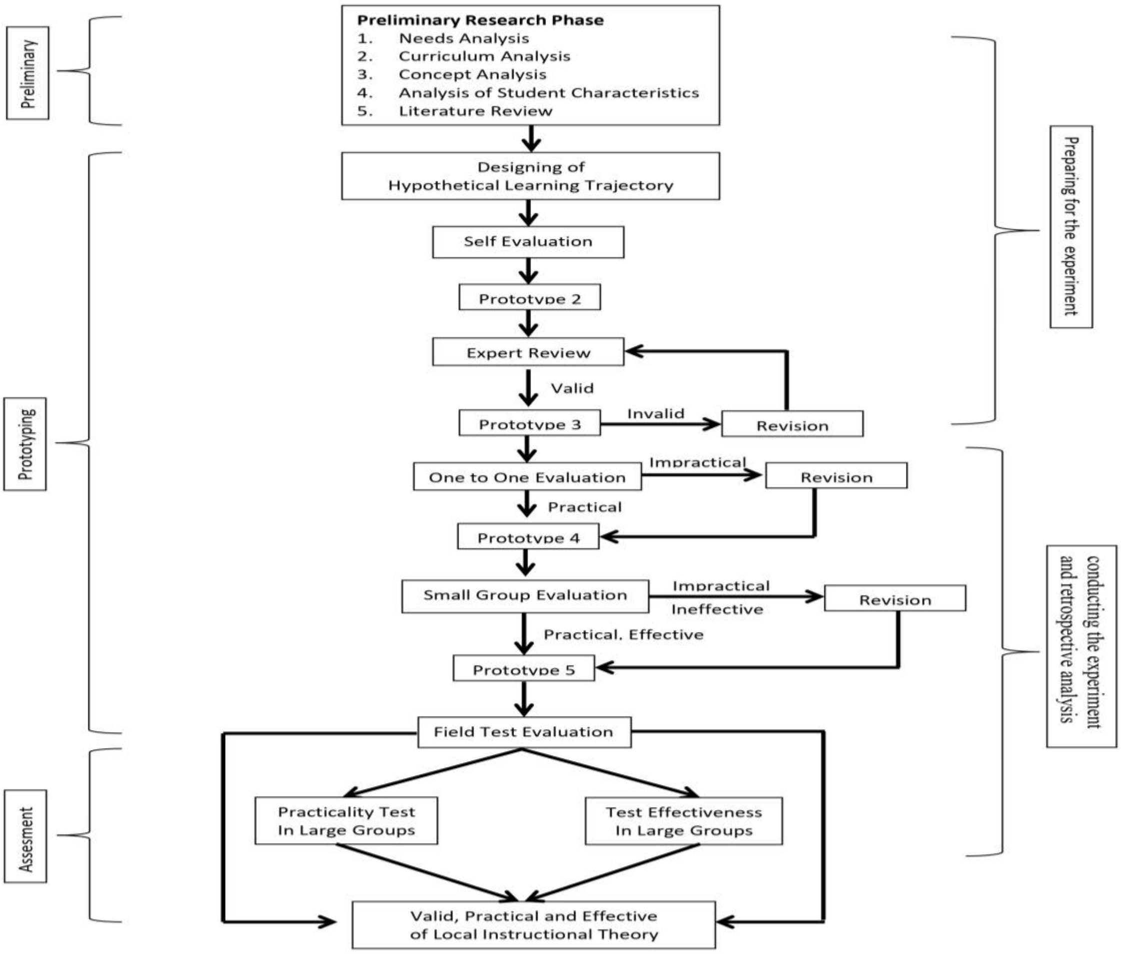


Figure 1. Research Procedure

RESULTS AND DISCUSSION

Results

This research starts from the initial investigation stage. At this stage, needs analysis, curriculum analysis, concept analysis, student characteristics analysis, and literature review were carried out. Based on the initial investigation results, it was found that a PBL-based learning flow with Jambi Malay ethnomathematics nuances was needed in trigonometry to improve students' mathematical communication skills.

The next stage is the stage of product development or manufacture. At this stage, the design and development of HLT were carried out, as well as a formative evaluation consisting of a self-evaluation stage to see the completeness of the developed components and an expert review stage to obtain data regarding the validity of the HLT.

Product Development Or Manufacture

At this stage, a Hypothetical Learning Trajectory (HLT) was designed. HLT consists of three components: learning objectives, learning activities, and learning process hypotheses (predictions of how students' thinking and understanding will develop in the context of learning activities), as well as teacher anticipation of predictions of students' thinking (Simon, 2014). Determination of learning objectives is carried out at the beginning of learning, then followed by a series of several activities accompanied by predictions of student answers and trigger questions as the teacher's anticipation of student answers in each activity. Trigger questions are given to stimulate students' thinking in solving problems given in each activity to achieve learning objectives.

The learning flow in this study is designed for one meeting with the topic of trigonometry, which focuses on the sine rule subtopic. In the learning flow, two activities present problems related to Trace Jambi. The first activity is to determine the side lengths of the Jambi Trace pattern using the sine ratio with the help of the height line of the triangle. This activity aims for students to understand the sine rule through the height of an arbitrary triangle. This activity asks students to describe the appropriate triangle through a given contextual problem. Then, based on what is known from this problem, students are asked to be able to determine the side lengths of the Jambi Track motif, which is in the form of an arbitrary triangle, knowing the sizes of the two angles and the length of a side in the Jambi Track motif, as shown in Figure 2 below.

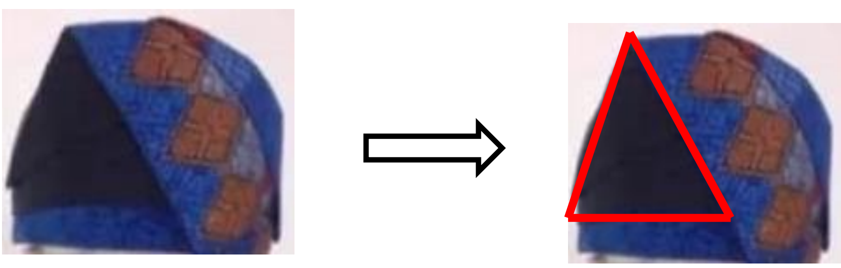
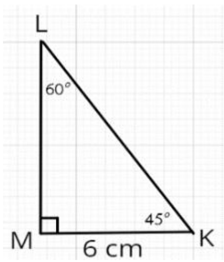
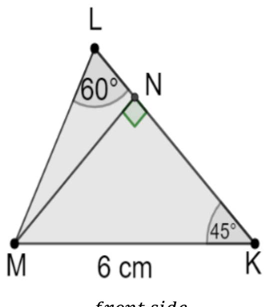


Figure 2. Lacak Jambi

Students can observe triangular shapes through the illustrations of the Jambi Tracks given. Tracing Jambi or Jambi Malay men's headbands is used as an object of observation because Tracing Jambi is close to the student's environment, so it can lead to students' understanding in determining the concept of the sine rule. The HLT is designed to contain predictions and anticipation of student answers. The prediction and anticipation of student answers in the first activity, which can be seen in Table 2.

Table 2. Prediction and Anticipation of Student Answers

No.	Prediction	Anticipation
1	Students need clarification in understanding the questions given.	The teacher guides students to write down the information on the problem and then directs students to make a suitable triangle image. The teacher gives a trigger question: "The triangle drawn is not a right angle, while the concept of trigonometry must use a right triangle; what is the solution so that there are right triangles in the triangle? Do we need to add new lines, such as heights or weights, to make a right triangle appear?"
2	Students understand and describe a triangle from the given problem, but students describe a triangle that does not match the picture.  Tan L = $\frac{front\ side}{corner\ side}$ Tan L = $\frac{KM}{LM}$ Tan 60° = $\frac{6}{LM}$ $\sqrt{3} = \frac{6}{LM}$ LM × $\sqrt{3}$ = 6 LM = $\frac{6}{\sqrt{3}} \times \frac{\sqrt{3}}{\sqrt{3}} = \frac{6}{3}\sqrt{3}$ LM = $2\sqrt{3}$ cm So the length of the left side is $2\sqrt{3}$ cm.	The teacher asks students to check the problems given. The teacher gives a trigger question: "Is the black decoration in the shape of a right triangle? What are the characteristics of a right triangle? If it is not a right triangle, while the concept of trigonometry must use a right triangle, what is the solution so the triangle has a right triangle? Do we need to add new lines such as heights or weights to make a right triangle appear?"
3	Students can solve the problems given correctly by using height lines and sine ratios.  Sin K = $\frac{front\ side}{hypotenuse}$ Sin K = $\frac{MN}{KM}$	The teacher gives awards to students for being able to determine the length of the left side of the Jambi Track correctly.

Sin 45º = $\frac{MN}{6}$
MN = Sin 45º x 6 ……(1)
Sin L = $\frac{front\ side}{hypotenuse}$
Sin L = $\frac{MN}{LM}$
Sin 60º = $\frac{MN}{LM}$
MN = Sin 60º x LM …(2)
Substitute (1) to (2) then:
MN = Sin 60º x LM
Sin 45º x 6 = Sin 60º x LM
$\frac{1}{2}\sqrt{2} \times 6 = \frac{1}{2}\sqrt{3} \times LM$
$3\sqrt{2} = \frac{LM\sqrt{3}}{2}$
LM $= \frac{3\sqrt{2} \times 2}{\sqrt{3}}$
LM $= \frac{6\sqrt{2}}{\sqrt{3}} \times \frac{\sqrt{3}}{\sqrt{3}}$
LM $= \frac{6\sqrt{6}}{3} = 2\sqrt{6}$ cm
So the length of the left side is $2\sqrt{6}$ cm

The second activity is formulating the sine rule through the problems in the first activity. This activity aims to formulate the sine rule based on the relationship of the three altitudes in a triangle. In this second activity, students can use any triangle in the first activity, as shown in Figure 3 below.

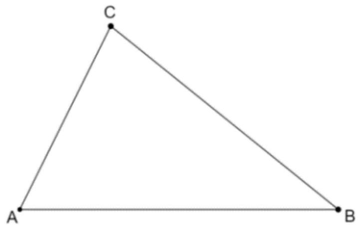
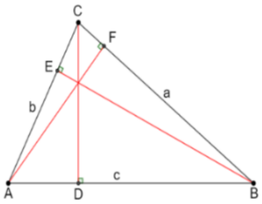
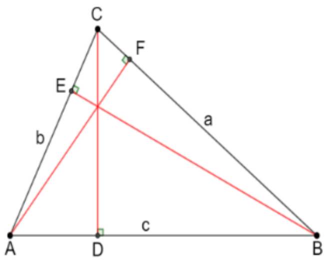


Figure 3. Triangle

After knowing and paying attention to these arbitrary triangles, students are directed to draw the height line of each vertex. Student activities are continued with students being directed to complete each blank section provided according to students' understanding of the material previously studied. In the final stage, students will be asked to conclude the concept of the sine rule they found, while the teacher's role is to check the truth of the conclusions students find. The following is a prediction and anticipation of student answers in the second activity, which can be seen in Table 3.

Table 3. Prediction and Anticipation of Student Answers

No.	Prediction	Anticipation
1	Students need clarification in understanding the problems given.	The teacher guides students to draw height lines on triangles. The teacher gives a trigger question in the form of: "Which one is ΔCAD? Which side is needed to get the value of Sin A? Which one is ΔCBD? Which side is needed to get the value of Sin B? From the two equations, what is obtained?
No.	**Prediction**	**Anticipation**

2	Students are correct in drawing height lines and writing complete information from problems on triangles. However, students are still writing comparisons of sines, so errors occur in finding the sine rule.  For ΔCAD Sin A = $\frac{AD}{b}$ $AD = b\,sin\,A$ .... equation 1 For ΔCBD Sin B = $\frac{BD}{a}$ $BD = a\,sin\,B$ .... equation 2 From equation 1 and equation 2 then: a sin B = b sin A $\frac{a}{sin\,A} = \frac{b}{sin\,B}$ .... equation 3	The teacher asks students to recheck the trigonometry comparisons. The teacher gives trigger questions: "Look again at our previous material about trigonometry comparisons; how do you find the value of the sine of an angle? Which sides are needed?"
3	Students can solve the problems given correctly by using height lines and sine ratios.  For ΔCAD Sin A = $\frac{CD}{b}$ $CD = b\,sin\,A$ .... equation 1 For ΔCBD Sin B = $\frac{CD}{a}$ $CD = a\,sin\,B$ .... equation 2 From equation 1 dan equation 2 then : a sin B = b sin A $\frac{a}{sin\,A} = \frac{b}{sin\,B}$ .... equation 3 For ΔABF Sin B = $\frac{AF}{c}$ $AF = c\,sin\,B$ .... equation 4 For ΔACF Sin C = $\frac{AF}{b}$ $AF = b\,sin\,C$ .... equation 5	The teacher gives awards to students for being able to solve the problems given correctly.

From equation 4 dan equation 5 then :
b sin C = c sin B

$\frac{b}{sin\,B} = \frac{c}{sin\,C}$ .... equation 6

From equation 3 and equation 6, it will be obtained:

$\frac{a}{sin\,A} = \frac{b}{sin\,B} = \frac{c}{sin\,C}$

Review of Experts

HLT was validated by 3 mathematician lecturers and 1 language expert lecturer. Aspects validated by experts are content and language aspects. The results of HLT validation by expert lecturers can be seen in Table 4 below.

Table 4. Overall HLT Validation Results

Rated Aspect	Average	Category
Content Aspect	3,37	Valid
Language Aspect	4,00	Very Valid
Overall Average	3,69	Very Valid

Based on Table 4, the results of HLT validation by the validator for the content aspect have a valid category and for the language aspect have a very valid category. Overall the developed HLT has a value of 3.69 with a very valid category. Furthermore, valid HLT was tested on students. After the trial was carried out, students were given questionnaires and tests and the results were obtained as shown in Table 5 and Table 6.

Table 5. Practicality Questionnaire Results

No	Aspects Assessed	Practicality Value (%)	Category
1	Ease of Use	81,94	Practical
2	Time efficiency	75	Practical
3	Attractiveness	83,33	Practical
4	Ease of Understanding	79,17	Practical
5	Benefits for Students	81,25	Practical
	Overall Average	**80,14**	**Practical**

Tabel 6. Recapitulation of Test Results

Ability Level	***Pre-Test*** Results			Total	Average	***Post-Test*** Results			Total	Average
	W	**D**	**ME**			**W**	**D**	**ME**		
High ability	8	3	9	20	62,50	16	16	15	47	97,92
Moderate ability	3	6	9	18	56,25	13	15	12	40	83,33
Low ability	4	4	7	15	46,88	13	13	12	38	79,17

Based on Table 5, it was found that the tested HLT met the practical category with a practicality value of 80.14. Furthermore, table 6 also shows that the designed HLT effectively improves students' mathematical communication skills for both low, medium and high ability students.

Discussion

The validity of the designed HLT has been tested with the results showing that this learning flow meets valid criteria on the content aspect and is very valid from the language aspect or it can be concluded that overall the designed HLT is in the very valid category. This shows that the designed HLT already has complete components, namely: learning objectives, student activities, and students' learning/thinking processes. Activities designed in HLT are appropriate to be used to achieve learning objectives by using contextual problems related to Jambi Malay culture. The designed HLT is in accordance with the PBL learning steps. The designed HLT has also been tested on six students and the practicality percentage of the product is 80.14% which is in the practical category. Thus, it can be concluded that HLT can be used in learning. The researcher also tested the effectiveness of HLT on the six students through a test of mathematical communication skills and found that there was an increase in the average percentage of students' mathematical communication abilities, both from low ability students, medium ability students, and high ability students. This shows that the designed HLT is effective in improving students' mathematical communication skills. Based on the discussion above, it can be concluded that the Trigonometry HLT based on Problem Based Learning with Jambi Malay ethnomathematics nuances has met the valid, practical, and effective categories. This study contributes to the existing body of knowledge by presenting strategies to enhance the mathematical communication abilities of students (Hidayat & Aripin, 2023; Ismail et al., 2023; Nasrullah et al., 2023; Rudianto et al., 2022; Sutama et al., 2023; Wijayanti et al., 2023). It offers innovative approaches and methods, integrating theoretical insights with practical applications, to foster enhanced learning outcomes in the realm of mathematics.

So far there has been no research linking Jambi Malay culture with Problem Based Learning on the topic of trigonometry so that this learning flow is a novelty in the world of education. This learning flow is adapted to the needs of students who are oriented towards trigonometry topics based on Problem Based Learning with Jambi Malay ethnomathematics nuances. This PBL-based learning begins with giving contextual problems so that students are able to find a concept (problem orientation). After students understand the problem given, students are directed to solve the problem in groups (student organizations). Solving this problem by utilizing prior knowledge and student experience as well as guidance from the teacher (guiding students). Problems that have been solved are then presented and discussed to then draw final conclusions about the learning that has been carried out (presentations, discussions and evaluation).

Implication

Trigonometry HLT based on Problem Based Learning with ethnomathematics nuances of Jambi Malay which is valid, practical and effective is expected to help teachers and students in learning mathematics.

Limitation and Suggestion for Further Research

Based on the direct experience that researchers have experienced, researchers need quite a long time in this research process, especially in the product manufacturing stage. The designed HLT also only focuses on one topic, namely the topic of trigonometry. therefore, it is suggested for future researchers to be able to design a similar HLT with a different topic.

CONCLUSIONS

Based on the results and discussion, it was found that the HLT that the researchers developed was valid, practical and effective and could be used in teaching mathematics for class X SMA on trigonometry. The designed HLT has been tested for the level of validity, practicality, and effectiveness which shows that the learning trajectory is valid both in terms of content and language, practical and effective for students to use. Suggestions for future researchers to be able to develop HLT on other mathematical topics.

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AUTHOR CONTRIBUTIONS STATEMENT

VH is the designer and implementer of the research. A as VH's supervisor in completing the research is an instrument manufacturer. IMA as a validator of the instruments used in research. Comments and suggestions from A and IMA are very important in this research.

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