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Realistic mathematics learning model based on Mandailing culture assisted by TPACK: model development study to develop critical thinking skills

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ABSTRACT

Introduction. Mathematics education is crucial in developing critical thinking skills for solving complex problems in various fields. However, the main obstacle to its implementation is the lack of understanding and training of teachers regarding relevant learning approaches using technology and integrating ethnomathematics elements. As a way to overcome this, TPACK is an important guide for teachers in effectively integrating technology into teaching practices as it can significantly support the development of mathematics learning models that combine culture with technology. There is a significant gap in the literature regarding mathematics learning models that effectively integrate local culture and technology, especially in the Mandailing cultural context. By developing a learning model that combines Mandailing culture and TPACK, educators are able to design a more interesting and effective learning environment. This study aims to develop a realistic mathematics learning model based on Mandailing culture assisted by TPACK media in developing students' critical thinking skills in mathematics subjects.

Participants and research methods. The subjects of the field trial activity involved 24 students and 2 teachers. There were 5 validators who gave assessments of the improvements to the products developed. The development model used was the Plomp model which included the stages of initial investigation, design, realization/construction, trial stage, evaluation and revision, and implementation. The instruments used comprised validation sheets, response questionnaires, and tests. Furthermore, data analysis involved qualitative and quantitative data analysis. Qualitative analysis was carried out with the steps of data reduction, data presentation, and drawing conclusions from the qualitative data. Meanwhile, quantitative data analysis involved descriptive and inferential statistical analyses. Descriptive analysis was carried out to describe the level of validity, practicality, and effectiveness of the products developed, while inferential statistical analysis with paired t-test statistical analysis was used to analyzed the level of effectiveness of improving students' critical thinking skills based on the Average Normalized N-Gain value.

Results. The development of a realistic mathematics learning model based on Mandailing culture assisted by TPACK had met the criteria of valid, practical, and effective. The product had an average valid assessment of 89.55 by 5 validators. Student responses to the application of the learning model was in the practical category with a percentage of responses from students 92.32 and from teachers 88.3. The effectiveness of the application of the learning model was reviewed based on the average achievement of students' critical thinking skills in mathematics in the pretest of 66.4 and the posttest of 81.7. The data obtained significance of (2-tailed) 0.00 < 0.05 and t-count> t-table (41.62> 2.064) provided a conclusion that there was a significant difference in the average between the pretest and posttest results with increase in critical thinking skills by 0.45 in the moderate category.

Conclusion. Learning activities using the developed model made students think more critically, thus creating a more meaningful and relevant learning experience that was in accordance with the research objectives. These objectives were developing a realistic mathematics learning model product based on Mandailing culture assisted by TPACK media that met the criteria of valid, practical, and effective in developing students' critical thinking skills in mathematics learning.

KEYWORDS

critical thinking, ethnomathematics, Mandailing culture, realistic mathematics, TPACK

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INTRODUCTION

Globalization and technological developments have created new challenges in education, which demand good critical thinking skills from students [1]. In the context of 21st-century education, critical thinking skills are very crucial for students to posses as to prepare them facing the complexity of an ever-changing world. Through critical thinking, students can find useful information, which enables them to make wise decisions based on available information [2]. In this digital era, students are expected not only to be able to understand information but also to be able to analyze, evaluate, and create solutions to complex problems [3; 4]. Therefore, education must adapt to this condition by integrating technology and learning models that encourage students to think critically and creatively in solving problems [5].

Mathematics education is crucial in developing critical thinking skills for the purpose of solving complex problems in various fields. Through a structured and systematic approach, mathematics education teaches concepts and procedures and encourages students to analyze, evaluate, and create innovative solutions [6]. A learning that provides an opportunity to develop these abilities is Realistic Mathematics Education (RME). RME views mathematics as a human activity, not just ready-to-use knowledge [7]. It utilizes the surrounding environment to generate thinking and provide the widest possible opportunities for students to understand mathematical materials [8]. Providing opportunities for students to learn mathematics in real-world contexts is crucial to providing a solid foundation for a mathematical topic [9; 10]. Furthermore, RME integrated with technology in education has been shown to be effective in improving students' critical thinking and problem-solving skills [11]. Thus, mathematics education not only functions as a tool for understanding numbers and formulas but also as a means to equip students with the critical thinking skills needed to face increasingly complex real-world challenges [12; 13] .

The challenges in learning mathematics in Indonesia are closely related to students' low critical thinking skills, which are a significant obstacle in dealing with complex problems. In addition, it was found that students lack interest in mathematics, and consider the subject as a difficult and boring subject, which can be observed in that there are students who have difficulty solving mathematics problems [14]. Furthermore, many students are still trapped in a rote learning pattern that does not encourage exploration and in-depth analysis of mathematical concepts [15]. This is exacerbated by the lack of use of interactive and technology-based teaching methods as a way to increase student engagement and stimulate their critical thinking skills [16]. In addition, the learning approaches commonly used by teachers tend to focus on direct teaching, often reducing students' opportunities to practice solving problems independently and creatively [12]. Therefore, to improve students' critical thinking skills in mathematics, reforms are needed in more innovative and collaborative teaching methods. Additionally, effective educational technology should also be integrated in the teaching and learning process.

However, one of the main difficulties is the lack of understanding and training of teachers regarding learning approaches that are relevant to the local cultural context, which can integrate ethnomathematics elements into the curriculum. However, many teachers are still confined to traditional methods that do not encourage exploration and critical analysis, hampering the students' development of these skills [15; 17]. In addition, limited access to educational technology that supports interactive learning also hinders teachers from making engaging learning for students, considering that technology can play an important role in creating more engaging and relevant learning experiences for students [18]. Therefore, implementing appropriate and effective learning approaches that are integrated with strong cultural richness, such as the Mandailing culture, can be used as an alternative to facing various significant challenges, especially in improving students' critical thinking skills.

Integration of local culture in learning has profound significance, especially in the context of education in Indonesia, where cultural diversity can be utilized to make learning materials more relevant and meaningful to students. Culture-based approaches, such as ethnomathematics, allow students to relate mathematical concepts to their everyday experiences and traditions, enhancing their understanding and interest in the materials being taught [19]. Studies have found that students learning mathematics through their cultural context can develop their academic skills and strengthen their cultural identity and self-confidence [20]. By integrating local cultural elements, such as community traditions and practices, into mathematics learning, it is possible for teachers to create more engaging and contextual learning experiences, improving student engagement and achieving learning outcomes in the process [21]. Therefore, educators must design curricula that meet academic standards and respect and utilize local cultural richness as a valuable educational resource [22].

The Mandailing cultural richness, including traditions, arts, and local wisdom [23], has great potential to be integrated into mathematics learning which can strengthen the relationship between the material taught and the students' socio-cultural context. The adoption of a culture-based approach makes mathematics education to become more relevant and meaningful [24], allowing students to see mathematics as part of their daily lives [25]. For example, the use of Mandailing cultural elements in learning can help students understand mathematical concepts through examples that are close to their experiences, such as activities carried out during the customs of birth events, wedding events, and death events. Therefore, educators need to design a curriculum that not only meets academic standards but also appreciates and utilizes the richness of Mandailing culture as a valuable educational resource. In turn, this can create a more holistic and contextual learning experience for students.

The TPACK (Technological Pedagogical Content Knowledge) framework is an innovative approach that integrates three main components, content knowledge, pedagogical knowledge, and technological knowledge, to create more effective and relevant learning experiences. TPACK is a complex knowledge for educators to integrate technology into education [26; 27]. Educators are highly expected to actively learn technology and how it can be effectively used in secondary school mathematics classes to enhance student learning activities [28; 29]. TPACK allows teachers to design and implement teaching strategies that focus on the material and consider how technology can support the learning process and enhance student understanding [18; 30]. Using TPACK, educators can identify the most appropriate tools and methods to deliver content and create an interactive and engaging learning environment for students [31]. Research shows that implementing TPACK in education can improve student engagement and learning outcomes, as this approach encourages the appropriate use of technology in teaching [32].

Furthermore, TPACK is an important guide for teachers in effectively integrating technology into their teaching practices, facilitating deeper and more meaningful learning for students. The TPACK framework can significantly support the development of mathematics learning models that combine the Mandailing culture with technology, thereby enhancing students' critical thinking skills. By utilizing TPACK, educators can design learning experiences that integrate mathematics content while also considering the rich local cultural context, such as the traditions and practices of the Mandailing community [33]. For example, using technological tools, such as the use of a projector to present interactive videos and student discussion results and provide other information with both PowerPoint media learning, can help facilitate learning activities and help students understand mathematical concepts better. Therefore, applying TPACK in the Mandailing culture-based mathematics learning was expected to enrich students' learning experiences and facilitate the development of skills needed to face challenges in the real world.

There is a significant gap in the educational literature regarding mathematics learning models that effectively integrate local culture and technology, especially in the Mandailing cultural context. Although several studies have explored ethnomathematics approaches and the use of technology in education, few have combined these two elements holistically to create a relevant and contextual learning model [25; 33]. Many existing studies focus more on technical or pedagogical aspects separately, without considering how local culture can enrich students' learning experiences and improve their critical thinking skills. In addition, providing practical guidance on effectively implementing the integration of culture and technology in the mathematics curriculum is also crucial to conduct as previous studies have yet to venture upon this matter, resulting in a lack of resources that educators can use [18]. Therefore, it is important to develop learning models that recognize the richness of Mandailing culture and utilize modern technology to create more engaging and meaningful mathematics learning experiences for students.

Furthermore, there is an urgent need to develop and test new learning models that integrate cultural approaches and TPACK, which is essential to improve student learning outcomes, especially in critical thinking skills. Although several studies have explored technology integration in mathematics education, few specifically have linked local culture with the TPACK framework to create contextual and relevant learning experiences. This gap indicates the need for further research that does not only focus on technical or pedagogical aspects separately but also considers how cultural elements can enrich the learning process and improve students' critical thinking skills. By developing learning models that combine Mandailing culture and TPACK, educators are able to design more engaging and effective learning environments, which in turn can help students relate mathematical concepts to their everyday experiences. Therefore, research that focuses on this innovation is urgently needed to meet the demands of 21st-century education and improve the quality of education in Indonesia.

From the previous description, it is deemed important to develop a realistic mathematics learning model assisted by TPACK to develop students' critical mathematical thinking skills. Therefore, this study aimed to develop a mathematics learning model based on the Mandailing culture with TPACK support to improve students' critical thinking skills. Additionally, this study is expected to contribute significantly to the development of mathematics education in Indonesia, especially in improving students' critical thinking skills, which are needed to face global challenges in the current digital era.

RESEARCH METHODS

1. Research Design

This developmental research aimed to develop a realistic mathematics learning model based on the Mandailing culture assisted by TPACK media that was deemed feasible for developing students' critical thinking skills in mathematics. Product development was carried out using a development model [34], which involved the following stages: preliminary investigation, design, realization/construction, test, evaluation and revision, and implementation. The preliminary investigation stage included activities to analyze materials, mathematics curriculum, student characteristics, and work plan analysis. In addition, an analysis of relevant aspects of the Mandailing culture was also conducted and applied in the developed learning model. Furthermore, the design stage included designing the product of the developed learning model, which comprised learning syntax, social learning system, principles of learning management reactions, and other learning support systems. In addition, the instruments were designed to support the research, such as learning model validation sheets, questionnaires on the practicality of learning models for both teachers and students, and instruments for testing students' critical thinking skills in mathematics.

The next stage was realization/construction. This stage aimed to realize the product that had been designed previously in the learning model product. The learning model in question contained the main components of the realistic mathematics learning model based on the Mandailing culture assisted by TPACK, which were developed including Rationale for Model Development, Supporting Theory for Model Development, characteristics, and components of Model Development, and Instructions for Implementing Learning through the developed model. Furthermore, test, evaluation and revision were conducted to determine the level of validity, practicality, and effectiveness of the developed learning model. In this case, a validator with expertise in mathematics learning based on culture and technology was asked to assess the learning model product. The activity of validating the model product by an expert was carried out from a theoretical rational perspective and consistency between model components internally. Then, the next step was the implementation stage, which aimed to apply the product that had been produced in the next stage, such as field trials and application to certain subjects. Furthermore, the achievement of the developed model product was reviewed in terms of validity, practicality, and effectiveness [35].

2. Respondents and Data Collection

The research respondents were at the analysis stage, the validator stage, and the field trial stage. In the analysis stage, respondents were interviewed to define the things needed to design the learning model. This analysis stage involved respondents, including 3 Mandailing cultural figures, 2 educational practitioners, and 3 junior high school students. This was done to collect qualitative data that aimed to describe the reality of the Mandailing culture that was relevant to learning activities at school, the conditions of students who were the subjects of learning mathematics, and the curriculum that applies or is applied to the research object school. Data was collected in the analysis stage using a semi-structured interview model [36]. Semi-structured interviews also allowed researchers to adjust questions based on the responses given to dig up further information that might not be previously expected.

Furthermore, there were 5 respondents involved in the validator stage. The validator was a respondent who provided an assessment, comments, and suggestions for improving the product being developed. Furthermore, respondents in the field trial involved teachers and students who were subjects in the field trial activities. The subjects of the field trial activity involved 24 students and 2 teachers. To measure the practicality of the learning model, students and teachers involved in the field trial were given a questionnaire [37]. An analysis of the effectiveness in terms of the pre-test and post-test achievements of students' critical thinking skills in mathematics was undertaken. This data was acquired to interpret the practicality and effectiveness of the products developed.

3. Data Analysis

Data analysis involved qualitative and quantitative data analysis. Qualitative analysis was used to analyze the results of interviews conducted with traditional figures, teachers, and students in the definition stage. The data were analyzed using several steps in accordance with the theory, including data reduction, data presentation, and conclusion or verification [38]. Furthermore, quantitative descriptive analysis was conducted to determine the achievement value of the Percentage Average Score (PAS) assessment of the level of validity and practicality of the developed model product. The achievement of the percentage average score assessment of the product was met if wat is at least in the fairly good category. The criteria for validity and practicality used were $86 \le PAS \le 100$: Very good; $76 \le PAS < 86$: good; $66 \le PAS < 76$: Enough; $56 \le PAS < 66$: Bad ; $0 \le PAS < 56$: Very bad.

The effectiveness of the developed product was scrutinized from the inferential statistical analysis of students' critical thinking ability tests in mathematics. The pretest and posttest results were analyzed using descriptive statistics, including mean, median, mode, standard deviation, variance, maximum, and minimum. Furthermore, the inferential statistical analysis was carried out using paired t-test analysis by ensuring that the data variance was normal and homogeneous [32; 39]. Furthermore, the achievement of students' critical thinking abilities was determined by the N-gain pretest against the posttest. After that, the level of effectiveness of the achievement of students' critical thinking abilities in mathematics was analyzed based on the Average Normalized N-Gain value by referring to the criteria for the level of effectiveness based on the normalized N-gain Meltzer [40] with the Interpretation of Effectiveness $N - gain < 0{,}3$ (Low), $0{,}3 \le N - gain < 0{,}7$ (medium), $N - gain \ge 0{,}7$ (high) [41].

STUDY RESULTS

1. Preliminary Investigation Stage

In the preliminary investigation stage, it was found that junior high school students applied the subject matter for grade seven mathematics lessons. They were number materials with sub-chapters on positive and negative numbers, addition and subtraction, multiplication, and division. The curriculum used was an independent curriculum that used a problem-based learning model. The learning abilities developed tended to lead to students' mathematical problem-solving abilities. Moreover, the learning activities were mainly conducted with the help of textbooks published by the government. The application of learning and problems raised in mathematics learning had not involved cultural aspects. The use of technology-based learning media in learning was also found to be less than optimal. In this contexts, the students were mostly 13 years old sitting in grade 7. Several students were enthusiastic about learning mathematics, while others consider mathematics less interesting and popular. From this findings, it was considered important to develop a learning model that involves cultural aspects with the help of the latest technology in mathematics learning, especially to develop students' high-level mathematical thinking skills.

In the Mandailing culture, society had noble values already embedded in each member's hearts, known as the ideal foundation of holong dohot domu (compassion and unity). Based on this ideal foundation, a structural foundation (lifeline) emerged that must be adhered to, consisting of patik (basic rules), uhum (explanation of patik), ugari (implementing regulations of uhum), and hapantunan (community ethics) [42; 43], other social ethics [44]. Based on the structural foundation, an operational foundation emerged involving the stages of pokat ulu ni tot (deliberation between two people/husband and wife), pokat sabagas (family deliberation), pokat saripe (extended family deliberation), pokat sahuta (village deliberation), and pokat godang (regional deliberation) which would ultimately produce domu ni tahi (agreement). In this case, problem-solving was carried out together, and conclusions were drawn based on agreement.

The relationship between members of society is carried out based on the philosophy of dalihan na tolu. Dalihan na tolu (Three Furnaces) is a unity of suhut/kahanggi (who have a job/friends of the same clan), anak boru (family who takes a wife from suhut's side), and mora (family from the wife's side). There are rules in the interaction relationship in dalihan na tolu which include respect mar mora, which is showing respect for mora, elek maranak boru, which is paying attention to anak boru, and rosu markahanngi, which is mutual kahanggi. The three elements of dalihan na tolu have the same level and have different roles in their duties [45; 46]. In this case, the relationship between members of society is collected in three roles that can change and must show an attitude of mutual respect and appreciation according to their position. Furthermore, in the Mandailing community, there are many daily activities in the form of traditional ceremonies and ornaments that involve cultural aspects. These traditional ceremonies include the birth of a child, marriage, giving a clan, death, etc. In addition, there are also ornaments of the Mandailing cultures, such as gordang sambilan (a drum musical instrument consisting of 9 pieces), marburangir (eating betel leaves), Salipi (a place to put traditional equipment), traditional cloth and others. These include activities that tend to be close to students and can be used as a context for problems in learning mathematics.

2. Design Stage

In the design stage, a realistic mathematics learning model product based on the Mandailing culture was carefully designed using TPACK to develop students' critical thinking skills in mathematics. The product design involved the syntax of the learning model, which involved communication to the delivery of objectives, benefits, models, stages of learning to be carried out, and displays apperception related to the association of the material to be studied with previous materials and presented in realistic problems and displayed through videos/moving images. Furthermore, the formation of learning groups was carried out to provide opportunities for students to interact in learning activities. Small groups were formed with group members who had the roles of kahanggi, mora, and anak boru. Then, the problems were given to group members who acted as suhut in each group, and the suhut group was directed to convey the problems given in their respective groups. Those who played a role in explaining the problems in their respective groups were group members who were positioned as suhut/kahanggi. Then, the teacher provided a general explanation to all groups in the class.

In solving and discussing problems, students in each group tried to solve the existing problem, and then continued by discussing the problem in each group. As for demonstrating problem-solving findings, the students presented the results of their problem-solving and group discussions in front of the class. In this case, the presentation of discussion findings was demonstrated in front of the class with the help of a computer, which involved an infocus in its presentation. This involved questions and answers between the presenting group and the existing audience. The dominant role, in this case, was assigned to the group members who were in the position of anak boru. Summarizing learning findings was done through the learning groups presenting the results of their findings regarding the problem-solving discussion found. Meanwhile, the role in conveying conclusions was done by the group member who was in the position of mora. In this case, the teacher emphasized and focused on the conclusions of the material being studied. Learning evaluation involved students who would be evaluated independently regarding their understanding of the learning activities.

It was also important to regard the social system or learning environment, namely the situation or atmosphere and norms that were applied in the Mandailing Culture-Based Learning Model assisted by TPACK. Teacher and student activities during learning followed the philosophy of holong dohot domu with the principle of dalihan na tolu. Moreover, student interaction in learning involved small groups consisting of ≥ 3 people. This group comprised students who acted as suhut/kahanggi, mora, and anak boru functions. The small groups comprised members with heterogeneous abilities, including high, medium, and low abilities in mathematics. The principle of reaction involved teachers providing scaffolding to manage learning activities. In this case, the teacher acted as a facilitator and motivator in learning activities. Meanwhile, students were seen as subjects in learning who played an active role in finding concepts, materials, and findings from learning activities independently and in groups. Furthermore, research instruments were also specifically designed to implement the developed learning model products.

3. Realization/Construction Stage

The results of the initial investigation and design phases are reflected and re-examined to be arranged and packaged more systematically to fulfill the realization/construction model of realistic mathematics learning based on the Mandailing culture assisted by TPACK in teaching students critical thinking skills. The products produced in this phase were the initial prototype of the learning model product and research support instruments. The initial prototype was regarded a feasible product for the next development stage.

4. Test, Evaluation, and Revision Stages

The learning model product used as an initial prototype was then validated by 5 validators. The validators were experts in mathematics education. They provided constructive assessments and suggestions for the learning model being developed. The assessments from the 5 validators can be seen in Table 1.

Table 1

Validator Assessment of Developed Components

No.	Validated components	Validator Assessment	
		Score	Percentage (%)
1.	Learning Model		
	Rationale	42/50	84,00
	Supporting Theory	67/75	89,33
	Syntax	104/125	83,20
	Social System	114/125	91,20
	Reaction Principle	157/175	89,71
	Supporting System	209/225	92,89
	Instructional Impact and Accompanying Impact	155/175	88,57
	Learning Implementation	112/125	89,60
	Learning Model Content	175/200	87,50
2.	Teaching Module		
	Format	67/75	89,33
	Language	85/100	85,00
	Content	154/175	88,00
3.	Students' Critical Thinking Ability Test in Mathematics		
	Content	119/125	95,20
	Language	137/150	91,33
	Question construction	120/125	96,00
	Test description	46/50	92,00

Based on Table 1, the validator's assessment was obtained in the valid category. In addition, comments and suggestions from the validator were also obtained, which were used to improve the developed learning model product. After the revision process was done based on the suggestions from the validators, it was continued with a product trial with one group pretest-posttest design. The trial involved a pretest, 4 learning activities, and a posttest.

The practicality of the learning model was reviewed from the questionnaire responses of teachers and students regarding the implementation of learning. The indicators of the questionnaire on the practicality of teaching materials in teacher responses included consistency, organization, attraction, simplicity, integration, and balance. The results of the questionnaire responses of 2 teachers involved in implementing the developed learning model were in the very practical category, as shown in Table 2.

Table 2

Student and Teacher Responses to the Implementation of Learning Models

No	Aspects addressed	Students		Teachers	
		Skor	%	Skor	%
1.	Initial learning activities	563/600	93,83	46/50	92,00
2.	Core activities				
	Communication and Apperception	547/600	91,17	40/50	80,00
	Formation of Study Groups	221/360	92,08	17/20	85,00
	Providing and explaining problems	320/360	88,89	25/30	83,33
	Solving and discussing problems	337/360	93,61	25/30	83,33
	Presenting and comparing findings	323/360	89,72	25/30	83,33
	Concluding learning findings	220/240	91,67	18/20	90,00
	Learning evaluation	329/360	91,39	28/30	93,33
3.	Final Activities	554/600	92,33	48/50	96,00
4.	Implementation of learning stages according to time allocation	115/120	95,83	9/10	90,00
5.	Teacher and student enthusiasm in learning	228/240	95,00	19/20	95,00

The students' responses to implementing the learning model with indicators such as the practicality questionnaire given to teachers were in the practical category. The effectiveness of implementing the learning model was reviewed based on the achievement of students' critical thinking skills in mathematics in the pretest and posttest. Furthermore, it generated an average pretest score of 66.4 and an average posttest score of 81.7. The achievement of students' pretest and posttest critical thinking skills can be seen in Figure 1.

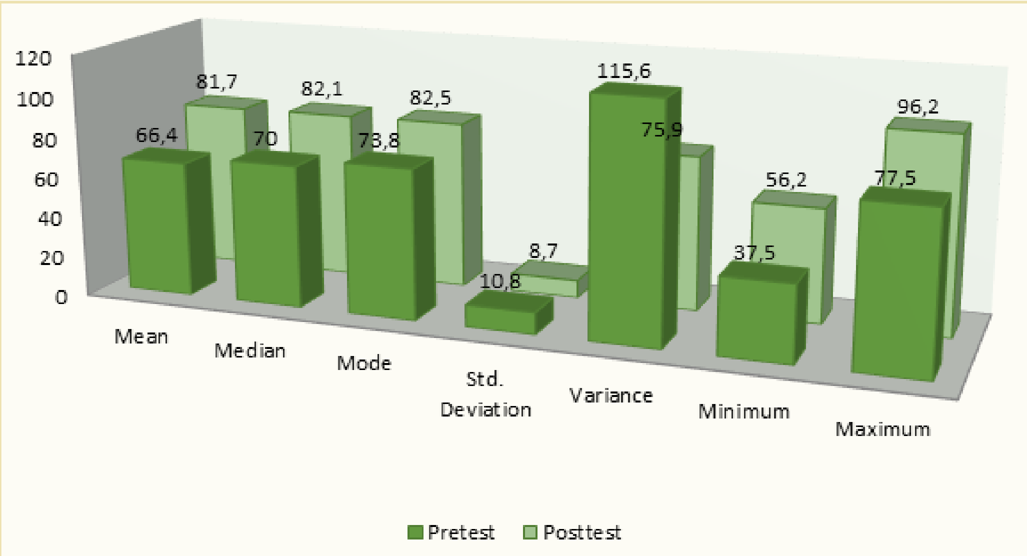

Figure 1 Students' Critical Thinking Ability Achievement in Mathematics

Based on the findings of critical thinking ability data of students in mathematics from 24 research samples, inferential statistical analysis was conducted. Inferential statistical analysis was conducted to test the normality and homogeneity of data variance with the help of the Statistical Package for Social Science (SPSS) software. Through the One-Sample Kolmogorov-Smirnov Test, Asymp. Sig. (2-tailed) pretest (0.459) and posttest (0.794) had greater values than the alpha level (0.05). Thus, the data obtained from students' critical thinking abilities were normally distributed. Furthermore, the data were analyzed using the Test of Homogeneity of Variances pretest-posttest data through Levene Statistic, and a significance of 0.184 was obtained, with an achievement greater than the alpha level. Based on the findings that the data variance was normally distributed and homogeneous, it was then continued with the paired t-test inferential statistical test. The output of the test can be seen in Table 3.

Table 3

Results of Paired Test Analysis –t-Test of Critical Thinking Ability in Mathematics

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest_CT Posttest_CT	57,71	9,61	1,39	54,92	60,50	41,62	47	0,00

Significance data acquisition (2-tailed) 0,00 < 0,05 and t-count > t-table (41,62>2,064) gave a verdict that there was a significant difference in the average between the pretest and posttest results. This means that applying research products significantly influenced students' critical thinking skills from the values through the pretest and posttest of critical thinking skills in the normalized N-gain acquisition of 0.45. This value provided an interpretation of the effectiveness of the medium category. Thus, it is concluded that applying learning model products effectively teaches students critical thinking skills in mathematics. The next stage was a further implementation of the use of the developed learning model. Socialization has been carried out with mathematics subject teachers, especially in the schools where the research was conducted to apply the developed learning model to teaching other mathematics materials that can be applied with the developed learning model.

DISCUSSION

The realistic mathematics learning model based on the Mandailing culture assisted by TPACK integrates various important aspects in the learning implementation process. Some syntaxes identified in this model included communication and apperception, which are crucial initial steps in learning. Through effective communication, teachers can link material to students' cultural experiences, thereby increasing the relevance of learning. At this stage, mathematical concepts are linked to local culture, and this aims to deepen students' understanding of mathematical concepts [25; 45]. In addition, good apperception helps students link new knowledge with existing knowledge, which is important for building a strong learning foundation [22]. The formation of study groups allows students to collaborate and learn from each other.

Through collaboration, critical thinking skills will improve [12; 47]. In this study’s context of the Mandailing culture, the formation of study groups can reflect existing social and cultural values, thus creating a more inclusive and relevant learning environment [48]. The next stage is the provision and explanation of contextual problems that can be presented in student worksheets. The problems given should be connected to daily real-life situations, which can increase student motivation and engagement in learning [11; 49]. Discussions and problem-solving in groups also provide opportunities for students to share perspectives and problem-solving strategies, which are important for developing collaborative skills [15]. The next stage is presenting and comparing findings. This process helps students understand various problem-solving approaches and strengthens their understanding of the studied mathematical concepts.

Furthermore, the presentation of discussion results trains students' communication skills and provides opportunities for reflection and feedback from peers and teachers [47; 49]. The last stage is learning evaluation. It is carried out by providing essay questions to measure students' critical thinking skills in mathematics according to the material being studied. This evaluation also provides constructive feedback to improve students' mathematical abilities to be better [12; 47]. These elements contribute to developing students' critical thinking and problem-solving skills, which are very important in mathematics education. Thus, the syntax of the realistic mathematics learning model based on the Mandailing culture in this study created a holistic, relevant, and contextual learning environment, which supported the development of students' critical thinking and problem-solving skills.

The validator's assessment of the realistic mathematics learning model product based on the Mandailing culture assisted by TPACK, which included components of the learning model, teaching module, and students' critical thinking ability test, showed that the validity was in the high category. The validity achievement of the learning model and teaching module and critical thinking ability also demonstrated that the product components presented had been well designed and in accordance with the principles of effective learning. This finding is in line with a study conducted by Mahmud et al. [15], which emphasizes the importance of validation in the development of products used in learning activities so that the products used can be ensured not only to meet academic criteria but also relevant and applicable in the real world context. The feedback provided by the validator serves as a basis for further improvement and development of educational products. In addition, another study by Pahrudin et al. [50] also revealed that the validity of the teaching material is in a good category and is very important for improving students' critical thinking skills.

Furthermore, teacher mastery of TPACK greatly influences the success of implementing technology in mathematics learning [29]. Thus, this product is not only relevant in terms of content but also in terms of the use of technology that supports the learning process. Finally, another study Valle & Junior [31] highlights the importance of understanding TPACK in developing teaching materials. These findings suggest that a good understanding of TPACK allows teachers to integrate technology validly in learning, which can improve the quality of education. Thus, this study provides a strong foundation for the argument that validating educational products involving validators' assessments can improve the quality and effectiveness of learning products in mathematics education.

The practicality of the developed learning model was reviewed based on the responses of students and teachers to learning. The research findings illustrate that all aspects requested from students and teachers are practical. Student responses to learning implemented through initial, core, and final activities show that the learning model received a positive response from students and increased student involvement in learning. This study's findings align with the findings of Samura and Darhim [16], which revealed that applying a learning model implemented with the help of technology can increase student motivation in learning mathematics. One study Valle & Junior [31] also shows that understanding TPACK among mathematics teachers can improve teaching practices. By utilizing technology effectively, teachers can create a more interactive learning environment and support the development of students' critical thinking skills. Furthermore, Irham et al. [51] point out that learning activities involving feedback and problem-solving can improve students' critical thinking skills. These activities create an active and interactive learning environment, which is very important to increase students' positive responses to learning.

Furthermore, implementing the learning stages also contributes to the applied model's practicality. The enthusiasm of teachers and students in learning is also an important indicator of the applied model's practicality. Kusaeri and Aditomo [17] explained that highly self-confident teachers can facilitate learning better, even though students experience difficulties. This shows that teacher enthusiasm plays a major role in creating a positive learning atmosphere in the class. Additionally, Lestari et al. [47] state that developing realistic mathematics education-based teaching materials can improve students' critical thinking skills. It is revealed that a relevant and contextual approach is crucial in mathematics learning. Overall, the practicality of the learning model developed can be seen from the students' positive responses, the good implementation of the learning stages, and the high enthusiasm of teachers and students. This further shows that the learning model is practical in improving students' learning experiences.

Applying the developed learning model was proven effective in improving students' critical thinking skills in mathematics in the current study. Applying this learning model allowed students to engage in real situations related to their culture. Furthermore, research shows that when students learn mathematics in contexts relevant to their daily lives, they can better understand and apply mathematical concepts critically [25; 52]. Using situations taken from the Mandailing culture, students can see how mathematics functions in their social and cultural contexts, increasing their motivation and engagement in learning [52]. In this case, students are motivated by problems that interest them, set in a meaningful context [24; 53]. The TPACK approach in this model emphasizes the use of technology in mathematics learning.

Technology integration also allows students to access wider and more diverse resources, and facilitates more interactive learning. Research shows that using technology in mathematics learning can improve students' critical thinking skills because they are encouraged to analyze information, evaluate sources, and make decisions based on available data [18; 31]. Thus, technology in mathematics learning functions as a tool and a medium that enriches students' learning experiences. Furthermore, this learning model also encourages collaboration between students. Collaborative learning effectively improves critical thinking skills because students can share ideas, discuss, and solve problems together [54; 55]. In the context of culture-based mathematics learning, this collaboration can strengthen students' understanding of mathematical concepts and develop their social and communication skills.

Through a learning process involving discussion, analysis, and evaluation, students can reflect on their understanding of mathematical concepts and how they are applied in their cultural context [56]. Overall, implementing the Mandailing Culture-Based Realistic Mathematics Learning Model assisted by TPACK could improve students' critical thinking skills in mathematics and create a more meaningful and relevant learning experience. By integrating local culture and technology, this model provides a strong foundation for students to develop critical thinking skills essential to facing real-world challenges.

Improving students' critical thinking skills is an important aspect of mathematics education, especially in culture-based learning, as proposed in this study. One of the main benefits of improving critical thinking skills is its ability to encourage students to analyze and solve problems effectively. In mathematics learning, an approach based on Realistic Mathematics Education (RME) effectively improves students' critical thinking skills. RME encourages students to engage in real situations relevant to their daily lives to develop critical thinking skills through direct experience [11; 47]. Meanwhile, collaborative learning involves student interaction and can increase their motivation and responsibility in the learning process [12]. Thus, a learning environment that supports collaboration and social interaction can also strengthen students' critical thinking skills.

Integrating technology in mathematics learning can also support the development of critical thinking skills. The use of technology in learning can significantly improve students' critical thinking skills, especially relating to mathematics. This is because technology can function as an effective tool in supporting mathematics learning and the development of critical thinking skills [16]. Technology can deepen students' understanding of mathematical concepts [4], and help students develop essential critical thinking skills [50]. Overall, improving students' critical thinking skills in mathematics through culture-based and technology-based learning models improves their understanding of mathematics and prepares them to face real-world challenges. Students can develop critical thinking skills essential for their academic success and daily lives by integrating elements of local culture, collaboration, and technology into learning.

CONCLUSION

In conclusion, the realistic mathematics learning model based on the Mandailing culture assisted by TPACK is an approach that needs to be applied in mathematics learning activities at the junior high school level, especially in teaching students critical thinking skills in mathematics. The learning model developed in this study involved seven phases in its core activities: communication and learning apperception, formation of study groups, providing and explaining problems, solving and discussing problems, presenting and comparing findings, concluding learning findings, and learning evaluation. Based on the trials conducted, the realistic mathematics learning model based on the Mandailing culture assisted by TPACK met the valid, practical, and effective criteria in teaching junior high school students critical thinking skills in mathematics. Learning activities using the developed model make students active and enthusiastic, creating a more meaningful and relevant learning experience.

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