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IoT-Assisted Realistic Mathematics Learning Based on Mandailing Culture: A Study of the Effectiveness of Learning Model Development in Improving Mathematical Computational Thinking Skills

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ABSTRACT

The problem and the aim of the study. The development of digital technology demands innovation in mathematics learning that focuses not only on cognitive abilities but also on students' computational thinking skills. however, the reality on the ground shows that mathematics learning in schools remains conventional, lacks contextualization, and fails to leverage the potential of local culture and technology fully. *The study aims* to describe the effectiveness of developing a realistic mathematics learning model based on Mandailing culture assisted by the Internet of Things (IoT) in improving students' mathematical computational thinking skills.

Research methods. The research was carried out using the Plomp model, which put an emphasis on the Assessment Stage. The data collection approach involved a quasi-experimental design with a pretest-posttest control group design. The study population comprised all seventh-grade students at SMP Negeri 3 Padangsidimpuan, divided into five study groups. The sample was then selected using a purposive sampling technique, with class VII-3 as the experimental class and class VII-4 as the control class, with 31 students in each class. The research instruments included observation sheets for learning management and tests for students' mathematical computational thinking skills. As for analyzing the data, it used descriptive analysis of the achievement of learning management and students' mathematical computational thinking skills. Furthermore, in gauging students' computational thinking skills, the study also conducted an inferential statistical analysis.

Results. The results showed that learning management obtained a score of 4.52, indicating a very effective criterion. The increase in computational thinking skills from pretest to posttest in the experimental class (24.79%) was higher than in the control class (17.94%). Furthermore, the significance value of the computational thinking skills of the experimental class with the control class was 0.00 <0.05 (alpha level) with a t-count of 3.407>2.000 (t-table). It was then concluded that there was a significant difference in the computational thinking achievements of the experimental class and the control class, while the n-gain value of the experimental class was 0.49 (moderate), which was better than the control class of 0.38 (moderate).

Conclusion. Thus, the IoT-assisted mathematical learning Based on Mandailing Culture is effective in improving mathematical computational thinking skills. Therefore, implementing the Mandailing Culture-Based Realistic Mathematics Learning Model, supported by IoT, can be an innovative strategy for integrating local culture and digital technology into mathematics learning to foster students' computational thinking skills effectively.

KEYWORDS

realistic mathematics, mandailing culture, internet of things; computational thinking; learning models

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INTRODUCTION

The Industrial Revolution 4.0 and Society 5.0 have significantly transformed education, notably regarding the necessity for proficiency in computational thinking as a fundamental talent for the 21st century [1; 2]. Such a fundamental skill is pertinent not only to information technology but must also be incorporated across several disciplines, including mathematics education [3]. In numerous developing countries, including Indonesia, the execution of educational practices that can enhance students' computational thinking abilities encounters significant obstacles, such as the absence of inventive, contextual learning frameworks and the restricted pedagogical application of digital technologies. Other than that, the success of future education will be decided not only by technological sophistication but also by the integration of local wisdom as a cultural identity in the learning process [4; 5]. Consequently, a pedagogical approach is required that is not only adaptable to technologies like the Internet of Things (IoT) but also profoundly anchored in local cultural values, thereby generating learning models that are both globally pertinent and locally significant.

Despite numerous national curriculum policies highlighting the significance of Higher Order Thinking Skills (HOTS)-based learning, the prevailing reality is that mathematics instruction in schools remains predominantly procedural, focused on rote memorization of formulas, with limited engagement in contextual problems that stimulate students' computational thinking abilities. There were studies in Indonesia indicating that many students struggle to decompose mathematical problems into algorithmic thinking frameworks [6; 7], while educators lack a systematic instructional model to support problem decomposition, pattern recognition, and solution representation grounded in computational logic. Conversely, the incorporation of technologies like the Internet of Things (IoT) in mathematics education is confined to the passive utilization of digital devices [8], rather than serving as a means to create interactive learning experiences grounded in direct observation of real occurrences. This state is further intensified by the unexploited potential of local knowledge, particularly Mandailing culture, as a repository of learning settings abundant in traditional numerical patterns, structures, and algorithms. Diverse elements of local wisdom, including artistic instruments, traditional attire, and the spatial organization of customary settlements, have important potential to serve as catalysts for enhancing students' computational thinking abilities [7]. Consequently, there is an imperative to propose a learning model that amalgamates the tenets of Realistic Mathematics Education (RME) and IoT technology, while also being grounded in local cultural wisdom, to foster a meaningful, adaptive, and effective learning process aimed at enhancing students' computational mathematical thinking skills.

Previous studies have investigated the efficacy of the Realistic Mathematics Education (RME) approach in enhancing students' mathematical competencies. However, most implementations remain confined to general realistic contexts, lacking explicit integration of local cultural dimensions [9]. Conversely, the utilization of Internet of Things (IoT) technology in mathematics education mostly emphasizes the visualization or display of digital data [10], rather than serving as a tool for mathematical inquiry through direct engagement with students' actual contexts. Moreover, while research has investigated the incorporation of local culture in education, the emphasis remains mostly on safeguarding ethnopedagogical values [11], rather than on using culture as a framework for enhancing computational thinking skills. No previous studies have been identified that concurrently incorporate RME, Mandailing culture, and IoT into a structured pedagogical framework to enhance students' computational mathematical thinking skills in a quantifiable and functional way. This lack represents a research gap that must be addressed by the creation and evaluation of learning models that are both methodologically creative and culturally pertinent, as well as technologically transformational.

Therefore, the present serves as a strategic importance as it provides tangible solutions to the global challenges of mathematics education in the digital age, specifically regarding the presentation of learning that is both adaptable to technological advancements and grounded in the strengths of local culture as the basis of student cognition. The incorporation of Realistic Mathematics Education (RME), cultural elements, and the Internet of Things (IoT) within a structured learning framework is anticipated to generate genuine, contextual, and interactive educational experiences, thereby enhancing students' computational thinking skills in a sustainable manner [12; 13]. Furthermore, this research theoretically advances RME studies into technology-enhanced ethnomathematics, a pedagogical method that integrates cultural reasoning with computational intelligence. The findings of this study are anticipated to provide a reference for educators, curriculum designers, and legislators in creating innovative and globally competitive mathematics education while preserving local identity. This research is pertinent not only to the Mandailing or Indonesian setting but can also be reproduced in other cultural contexts, aiming to enhance local wealth as a catalyst for computational literacy in the age of artificial intelligence.

This study seeks to evaluate the efficacy of the IoT-assisted Mandailing Culture-Based Realistic Mathematics Learning model in enhancing students' computational mathematical thinking skills, as revealed through the research gaps. It specifically evaluates the efficacy of the established model in enhancing students' computational thinking skills through implementation trials in educational settings. The primary contribution of the study is the introduction of a novel pedagogical framework that systematically integrates ethnomathematics, computational thinking, and IoT-enhanced learning, supported by empirical testing in mathematical learning design. The findings of this study are anticipated to enhance contemporary mathematics education theory and serve as a replicable model applicable across diverse cultural contexts, both nationally and globally.

THEORETICAL BACKGROUND

1. Realistic Mathematics Education

Since the 1970s, Utrecht University has maintained a research institute dedicated to enhancing mathematics education. The Freudenthal Institute, established by Hans Freudenthal, posited that mathematics, as a form of Realistic Mathematics Education (RME), is perceived as a human endeavor rather than a pre-existing knowledge [14]. RME was conceived from everyday life practices to enhance the enjoyment and significance of mathematics education for students by presenting contextual issues. Furthermore, RME facilitates the connection between mathematical concepts and real-world applications [15]. RME commences by addressing topics pertinent to students' experiences and understanding. It utilizes the surrounding environment to enhance cognitive processes and offers pupils extensive opportunities to comprehend mathematical concepts. Educators thereafter serve as facilitators to assist pupils in resolving contextual issues. Educators must exhibit dynamism, creativity, and innovation in lesson design, crafting learning tools, and resources that align with the instructional material and practical context [16]. The optimal method for instructing mathematics involves offering pupils relevant experiences through the resolution of everyday problems, or, in other terms, by tackling contextual issues.

RME in education encompasses three primary ideas as articulated by Freudenthal and Gravemeijer: Didactic phenomena, guided discovery, and model development [16; 17]. Gravemeijer delineates five characteristics of RME application in learning: (1) utilization of real-world contexts, (2) creation of models to convert original scenarios into mathematical problems, (3) students replicating the development of guided mathematical concepts, (4) interactions between students and teachers, and (5) perception of mathematics as an integrated discipline [16; 18]. Mathematics education will be more efficacious if students engage in the active processing and transformation of information. RME focuses on facilitating mathematization as a fundamental aspect of mathematics education. The implementation of RME in education alleviates students' difficulties in engaging with mathematical instructional materials [19]. This procedure encompasses two dimensions: horizontal and vertical mathematization. The former refers to the conversion of everyday problems into symbolic representations, whereas the latter involves processes conducted within the realm of symbols [20]. RME integrates these two methodologies to establish interrelation and sustainability. In essence, education commences with informal stages, guiding pupils to mathematize real-world issues through symbolic representation. Subsequently, students may progress to vertical mathematization, employing models to derive more generalizable conclusions.

2. Mandailing Culture

Mandailing is a community residing on the southwest coast of Sumatra, namely in Southern Tapanuli. The community's social structure is based on the principle of *Dalihan Natolu*, which encompasses three kinship elements: *mora* (wife's family), *anak boru* (husband's family), and *kahanggi* (family relatives) [21]. *Dalihan Natolu* literally signifies a three-legged stove that mutually supports and interlinks each sub-ethnic group, hence fostering a robust tie among them. It also represents a coalition of three indigenous tribes together to address various challenges [22]. Three conventions that constitute the ethics of Mandailing society, as per *Dalihan Natolu*, are honoring *mora*, welcoming *anak boru*, and exercising caution with *kahanggi (suhut)* [23]. The Mandailing community's traditional existence is founded on the notion of *Dalihan natolu*, which stipulates a monarchy governed by a king. The king is regarded as significant and esteemed, safeguarding his subjects with equity and benevolence. The king and his aides offer support and safeguarding to their subjects concerning life's challenges, both ethical and material. Implementing the principle of *dalihan natolu*, a social structure founded on *olong* (compassion), will foster *marsiolongan* (mutual affection), *leading to atigoran* (honesty). Similarly, domu will cultivate *adomuan* (unity), resulting in *adamean* (peace) [24]. The Mandailing customary legal system, grounded in *dalihan natolu*, facilitates *mardomu tahi* (deliberation and consensus), hence simplifying complex issues and resolving challenges effectively.

Dalihan natolu is identified as a framework consisting of three elements (*suhut, anakboru,* and *mora*) that form a social structure. It is also communicated that transparency within kinship groups will foster olong (compassion) and domu (unity) [25]. This love and solidarity will forge a strength applicable in different facets of life [26]. The Mandailing people conduct numerous aspects of their lives according to the principle of *dalihan natolu*, employing social systems such as genealogy, *marsialapari* (mutual collaboration), and engaging in discourse, among others. This social system is utilized in numerous ceremonial activities within communal life, including birth ceremonies, weddings, and funerals [27], as well as in the realm of education. The incorporation of Mandailing culture enhances the quality of educational activities. Furthermore, the education provided would instill positive cultural values in kids, enabling them to preserve their identity amidst globalization. Local cultural wisdom serves not only as an educational resource but also as a conduit for students to deepen their understanding and connection to the cultural values of their region [28].

3. Internet of Things

The Internet of Things represents a novel paradigm shift in the information technology sector. The term "Internet of Things," abbreviated as IoT, is composed of two words: "Internet" and "Things." The Internet is a worldwide network of interconnected computer systems that utilize the standard Internet protocol suite (TCP/IP) to service billions of people globally [29]. It is a vast network of interconnected networks, encompassing millions of private, public, academic, business, and governmental networks, ranging from local to global scales, linked by diverse electronic, wireless, and optical networking technologies [30]. As for 'Things', they denote any entity or individual that may be differentiated from the tangible world. Everyday items encompass not only the electronic devices utilized daily and advanced technological products [31], such as appliances and gadgets, but also objects typically not regarded as electronic such as food, clothing, furniture, materials, components, equipment, merchandise, specialty items, landmarks, monuments, works of art, and all manifestations of commerce, culture, and sophistication. This indicates that entities in this context may be sentient organisms. At this juncture, objects are tangible entities in the physical or material realm.

The Internet of Things is a vast and inclusive network of intelligent devices capable of autonomously organizing, sharing information, data, and resources, as well as responding and acting in reaction to situational and environmental changes [32]. Furthermore, it amalgamates physical and virtual entities into a worldwide network, profoundly influencing daily existence and overall quality of life. The Internet of Things is evolving and remains the latest and most exaggerated concept in the IT sector. In the last 10 years, the phrase Internet of Things (IoT) has garnered interest by envisioning a worldwide framework of interconnected physical entities, facilitating ubiquitous connectivity for any object, not merely for individuals [30; 33]. It can also be conceptualized as a global network facilitating communication among individuals, between individuals and objects, and among objects themselves, by assigning a unique identity to each entity [34]. The IoT envisions a society in which nearly all objects may link and communicate more intelligently than ever before.

4. Computational Thinking

The notion of computational thinking is now prevalent among students, scholars, and professionals across diverse disciplines, including mathematics education, natural sciences, social sciences, and other educational domains [35]. This type of thinking is seen as an essential talent in the contemporary digital era. With technological advancements and the pervasive use of computers across numerous domains, computational thinking has become essential. Computational thinking is characterized as a systematic and logical approach to problem-solving [36]. This skill is advantageous for pupils in resolving mathematical issues. In actuality, pupils frequently lack the capacity to utilize abstract concepts for solving mathematical problems and to apply algorithms correctly [37]. Computational thinking involves deriving answers to problems from input data through algorithms and employing techniques utilized in software development for programming.

Computational thinking is applicable not only in computer science but also across several other areas, including mathematics. Mathematics is the appropriate discipline for cultivating computational thinking skills, as it instructs students to approach problem-solving through logical patterns [38]. Computational Thinking encompasses cognitive competencies in mathematics education and cultivates pupils' capacities for advanced reasoning. There are four indicators of computational thinking [37,38]: (1) Decomposition, where students identify known and requested information from existing problems; (2) Pattern recognition, where students discern similar or discordant patterns to facilitate problem-solving; (3) Abstraction, where students derive conclusions by eliminating extraneous elements during the implementation of problem-solving strategies; (4) Logarithmic thinking, where students articulate the logical steps employed in deriving solutions.

RESEARCH METHODS

1. Research Design

This study was a development investigation utilizing the Plomp model [39], concentrating on the Assessment Stage. It sought to evaluate the efficacy of a realistic mathematics learning model, rooted in Mandailing culture and supported by IoT, in enhancing students' mathematical computational thinking abilities. The research efforts encompassed quasi-experimental research utilizing a pretest-posttest control group approach [40]. The research design is illustrated in Table 1.

Table 1 Research Design

Experiment group	O_1	x	O_2
Control group	O_1		O_2

2. Respondents and Data Collection

The research population comprised all seventh-grade students of SMP Negeri 3 Padangsidimpuan, organized into five study groups. Additionally, samples were obtained from this group utilizing a purposive sampling method, specifically from class VII-3 comprising 31 students and the control class, class VII-4, consisting of 31 students. The research instrument comprised a learning management observation sheet and an assessment tool for evaluating students' mathematical computational thinking skills. The learning management observation sheet was an evaluative document completed by observers throughout four sessions of learning activities utilizing the developed model product. Learning management was evaluated using indicators of learning stages, which encompass Initial Activities, Core Activities, Closing Activities, Time Management, and Classroom Atmosphere/Classroom Mastery. This activity entailed a learning management framework that encompassed the stages of communication and apperception, formation of study groups, problem presentation and explanation, problem solving and discussion, presentation and comparison of findings, summarization of learning outcomes, and learning evaluation. The evaluation of the observed components was conducted utilizing a Ricard scale with a scoring range of 0 to 5.

Additionally, there was a mathematical computational thinking ability assessment of four pretest and posttest questions. The instrument for assessing mathematical computational thinking capacity comprised grids, question scripts, scoring rules, and answer keys. The markers of computational thinking aptitude encompass Decomposition, Pattern Recognition, Algorithmic Thinking, and Generalization/Abstraction. Each test comprises four questions that have undergone validation and reliability assessment. The validity and reliability assessment of the test items was conducted in class VIII-7 at SMP Negeri 3 Padangsidimpuan, involving 30 students. The outcomes of the computational thinking tool testing are presented in detail in Table 2.

Table 2 Analysis of Validity Results

Pretest				Posttest			
No.	Correlation	Sig.	Conclusion	No.	Correlation	Sig.	Conclusion
1	.541**	.002	Valid	1	.637**	.000	Valid
2	.777**	.000	Valid	2	.695**	.000	Valid
3	.863**	.000	Valid	3	.685**	.000	Valid
4	.836**	.000	Valid	4	.812**	.000	Valid

Table 2 indicates that the pretest and posttest items for computational thinking skills satisfied the validity criteria. The items precisely evaluated computational thinking skills in accordance with the construct being examined. The dependability of the items was subsequently assessed using dependability statistics, with the results presented in Table 3.

Table 3 Results of the Reliability Statistics Test

Test	Cronbach's Alpha	Conclusion
Computational Thinking Pretest	.762	Reliabel
Computational Thinking Posttest	.756	Reliabel

Table 3 indicates that the reliability scores for both the pretest and posttest were within acceptable parameters. The pretest and posttest items for mathematical computational thinking ability reliably assessed students' competencies and can be regarded as a dependable evaluation instrument.

3. Data Analysis

The data analysis of the research findings encompassed descriptive statistical analysis of learning management outcomes and mathematical computational thinking skills, while inferential statistical analysis was performed on students' mathematical computational thinking abilities. Descriptive statistical methodology sought to uncover data centrality phenomena, including mean, median, mode, and standard deviation. The data centering accomplishment was analyzed by the subsequent interpretation: The determination of learning management achievement was based on the average assessment score, with the subsequent interpretations: $0 < \text{score} \leq 1.5$: Very Poor; $1.5 < \text{score} \leq 2.5$: Poor; $2.5 < \text{score} \leq 3.5$: Sufficient; $3.5 < \text{score} \leq 4.5$: Good; $4.5 < \text{score} \leq 5.0$: Very Good [25]. Additionally, inferential statistical analysis was performed to assess the enhancement of students' computational thinking skills. The assessment of accomplishment enhancement was conducted utilizing the Normalized Gain (N-gain) algorithm [41]. The N-gain acquired by the experimental and control groups was assessed for normality and homogeneity, and thereafter evaluated against the formulated hypotheses:

H_0 = There is a significant difference in the N-gain of students' computational thinking abilities in the experimental class and the control class.

H_a = There is a significant difference in the N-gain of students' computational thinking abilities in the experimental class and the control class.

The criteria for the rejection and acceptance of the suggested hypothesis were to reject H0 if the significance is greater than 0.05 or if the t-count is less than the t-table value, and to accept H0 if the significance is less than 0.05 or if the t-count exceeds the t-table value. The efficacy level is assessed according to the criteria derived from normalized N-Gain [84], with the following interpretations: N-Gain Score < 0.3 indicates Low efficacy, 0.3 ≤ Score < 0.7 signifies Medium Effectiveness, and 0.7 ≤ Score > 1.0 denotes High Effectiveness.

STUDY RESULTS

The research findings encompassed observations of learning management and students' computational mathematical thinking skills, as per the research model and methodology. Learning management observations were carried out during four meetings, each lasting 80 minutes and attended by an observer. Figure 1 illustrates the outcomes of the learning management observations.

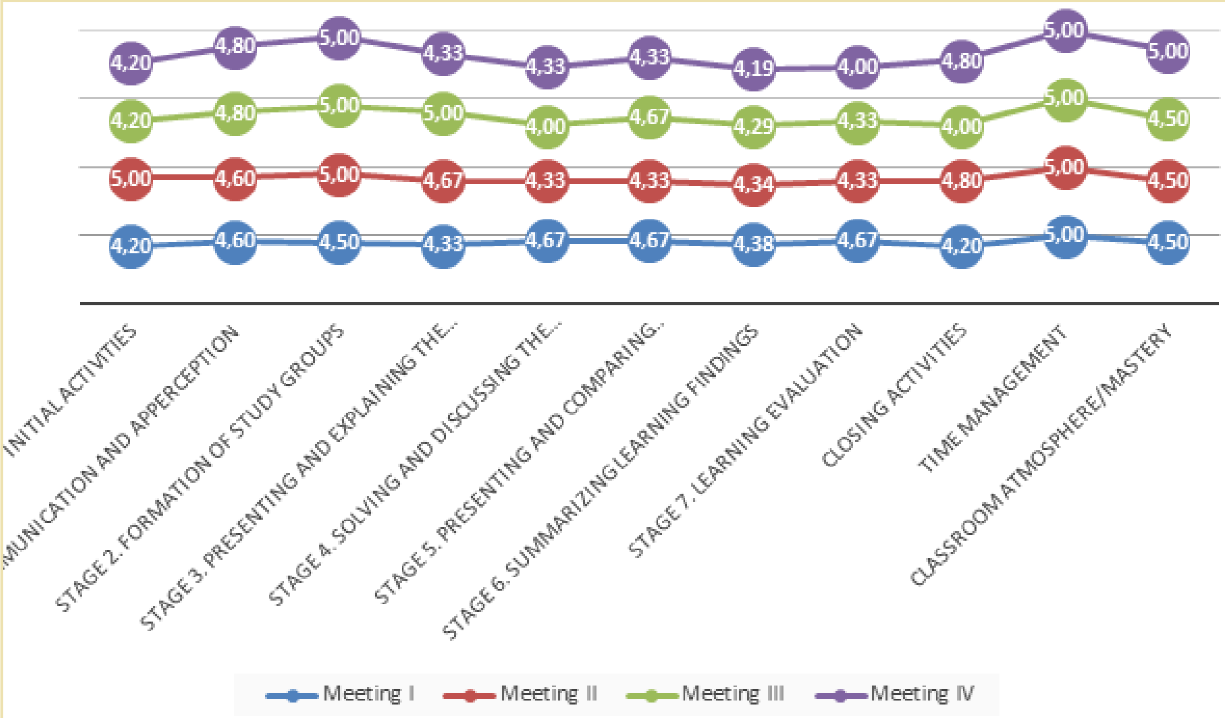

Figure 1 Learning management assessment graph in 4 meetings

The data in figure 1 indicates that the minimum achievement was 4.00 (Good criteria) and the maximum achievement was 5.00 (Very good criteria). Consequently, the attainment of the observed aspects in the learning activities fell within the good and very good categories. The results of this study align with the subsequent study, as evidenced by the average performance of each indicator across the four sessions, illustrated in Figure 2.

The prior figure indicated that the learning management performance across all observable aspects during the four meetings ranged from 4.30 to 5.00. The lowest achievement was in the summarizing learning findings category, classified as good, while the best achievement was in time management, classified as very good. The overall average performance across all observed aspects was 4.57, categorizing it as very good. The administration of realistic mathematics education, grounded in Mandailing culture and supported by IoT, effectively enhances students' computational thinking skills, categorizing it as very good. This finding aligns with the research of Ahmad et al. [25] which demonstrated that the management of realistic mathematics learning rooted in Mandailing culture during the four sessions achieved an average score of 4.41, categorizing it as good. Similarly, the research conducted by Ahmad et al. [24] indicates that the implementation of the realistic mathematics learning model, grounded in Mandailing culture, demonstrates effective criteria and a higher level of efficacy compared to the control class, as assessed by student activities. In summary, learning management is highly effective, demonstrating that all educational components, from comprehension to assessment, are administered proficiently, bolstered by optimal time and classroom management, thereby fostering an environment conducive to the enhancement of students' computational thinking skills.

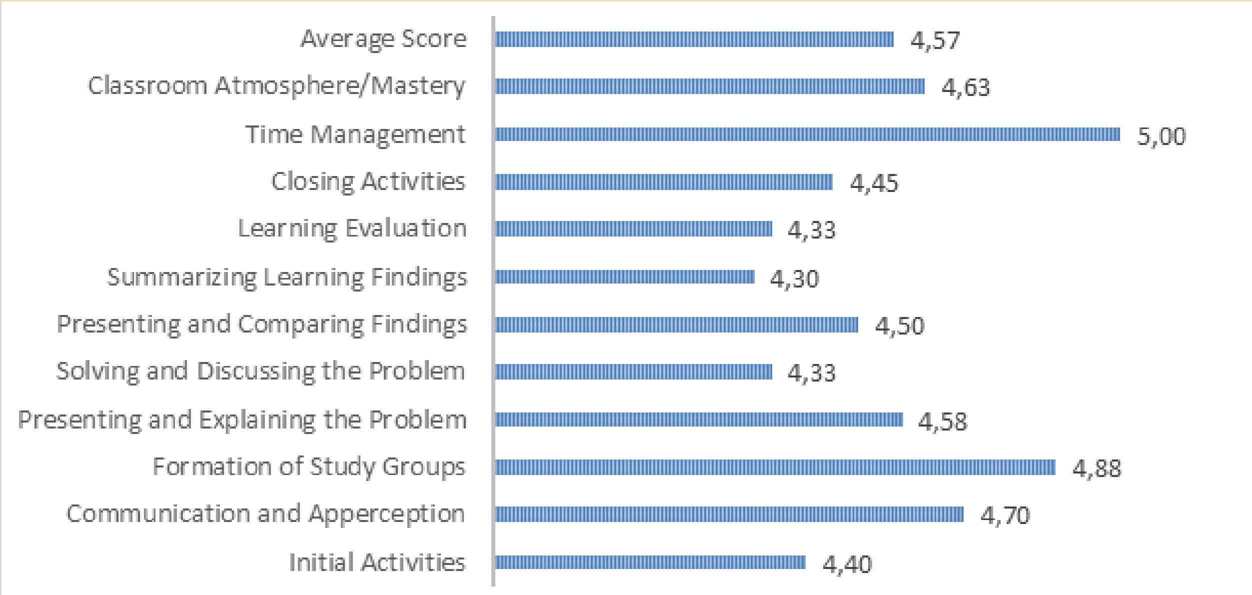

Figure 2 Average value achievement of aspects observed in learning

In conjunction with the learning management, pre-test and post-test data were collected on students' computational mathematical thinking skills. The analysis of computational mathematical thinking skills was conducted using pre-test and post-test scores, each comprising four items. The descriptive statistical study of students' computational mathematical thinking ability is presented in Table 4.

Table 4 Descriptive Statistical Examination of Computational Thinking Skills

Information	Experimental Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
N	31	31	31	31
Mean	66.53	83.02	68.55	80.85
Median	67.19	82.81	68.75	81.25
Mode	56.25	85.94	64.06	79.69
Std. Deviation	8.42	7.48	6.87	5.27
Variance	70.93	55.94	47.17	27.82
Range	37.50	39.06	28.13	21.87
Minimum	48.44	59.38	51.56	71.88
Maximum	85.94	98.44	79.69	93.75

The descriptive statistical analysis presented in Table 3 indicates that the mean value in the experimental class rose from the pretest score of 66.53 to the posttest score of 83.02, reflecting an increase of 24.79%. Additionally, in the control group, the mean score in the pretest (68.55) increased in the posttest (80.85), indicating an increase of 17.94%. In this instance, descriptively, the improvement in the experimental group surpassed that of the control group. The attainment of computational thinking skills in both the experimental and control classes was assessed using the N-gain of each student. The N-gain for each student is presented in Table 5.

Table 5 N-gain Achievement of Students' Computational Thinking (CT) Skills

Experimental Class		Control Class	
Student Code	N-Gain	Student Code	N-Gain
Eks_CT-01	0.39	Cont_CT-01	0.11
Eks_CT-02	0.93	Cont_CT-02	0.50
Eks_CT-03	0.05	Cont_CT-03	0.41
Eks_CT-04	0.42	Cont_CT-04	0.13
Eks_CT-05	0.46	Cont_CT-05	0.38
Eks_CT-06	0.45	Cont_CT-06	0.35
Eks_CT-07	0.17	Cont_CT-07	0.31
Eks_CT-08	0.72	Cont_CT-08	0.35
Eks_CT-09	0.38	Cont_CT-09	0.52
Eks_CT-10	0.56	Cont_CT-10	0.88
Eks_CT-11	0.44	Cont_CT-11	0.24
Eks_CT-12	0.47	Cont_CT-12	0.40
Eks_CT-13	0.28	Cont_CT-13	0.41
Eks_CT-14	0.67	Cont_CT-14	0.38
Eks_CT-15	0.55	Cont_CT-15	0.24
Eks_CT-16	0.06	Cont_CT-16	0.26
Eks_CT-17	0.14	Cont_CT-17	0.26
Eks_CT-18	0.33	Cont_CT-18	0.08
Eks_CT-19	0.29	Cont_CT-19	0.33
Eks_CT-20	0.52	Cont_CT-20	0.46
Eks_CT-21	0.48	Cont_CT-21	0.07
Eks_CT-22	0.35	Cont_CT-22	0.39
Eks_CT-23	0.50	Cont_CT-23	0.30
Eks_CT-24	0.48	Cont_CT-24	0.37
Eks_CT-25	0.45	Cont_CT-25	0.26
Eks_CT-26	0.26	Cont_CT-26	0.16
Eks_CT-27	0.47	Cont_CT-27	0.48
Eks_CT-28	0.32	Cont_CT-28	0.65
Eks_CT-29	0.71	Cont_CT-29	0.56
Eks_CT-30	0.63	Cont_CT-30	0.29
Eks_CT-31	0.19	Cont_CT-31	0.63
average n-gain	0.42	average n-gain	0.36

The N-gain achievement table indicates that the average N-gain value of the experimental class (0.42) surpasses that of the control class (0.36). The enhancement in computational thinking skills in the experimental group was more pronounced than in the control group. The N-gain in the mathematical computational thinking capacity of students from both the experimental and control classes was further scrutinized using inferential statistics using Statistical Package for the Social Sciences (SPSS) 22. Initially, a precursor analysis was conducted, which encompasses a normality test utilizing the Shapiro-Wilk method. The outcomes of the normalcy assessment are presented in Table 6.

Table 6 Normality Test Results

Information	Class	Kolmogorov-Smirnova			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
N-Gain_Pretest-Posttest_CT	1.00	.101	31	.200*	.979	31	.776
	2.00	.104	31	.200*	.977	31	.734

The Shapiro-Wilk normality test results indicate significance for the pretest at 0.776 and the posttest at 0.734, both exceeding the alpha level (α = 0.05). The n-gain pretest and posttest results of students' mathematical computational thinking abilities exhibited a normal distribution. The n-gain pretest and posttest successes of students' mathematical computational thinking abilities could be deemed normally distributed, as the growth adheres to an acceptable distribution pattern without significant deviation. The test of homogeneity of variances will proceed with the Levene statistical test. The outcomes of the homogeneity test are presented in Table 7.

Table 7 Homogeneity Test Results

Levene Statistic	df1	df2	Sig.
2.668	1	60	.108

The significance value derived from the homogeneity test was 0.108, exceeding the alpha level (0.108 > 0.05). It was indicated that the n-gain achievement of students' pretest and posttest mathematical computational thinking abilities was uniformly distributed. The enhancement of students' mathematical computational thinking skills from pretest to posttest transpired uniformly, with no substantial disparities across student groups. Consequently, the required assessments, including normality and homogeneity tests, had been satisfied, allowing for the execution of inferential statistical analyses utilizing parametric methods. The employed test was the independent samples test. The analysis findings are presented in Table 8.

Table 8 Independent Samples Test Results

t-test for Equality of Means		t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
N-gain Pretes-Postes_CT	Equal variances assumed	3.407	60	.001	.13581	.03986	.05608	.21553
	Equal variances not assumed	3.407	56.360	.001	.13581	.03986	.05598	.21563

The Independent Samples Test results indicated a Sig. (2-tailed) value of 0.001, which was below the alpha level of 0.05, and a t-count value of 3.407, exceeding the t-table value of 2.000. Therefore, it was concluded that a significant difference existed in the n-gain index between the experimental and control classes. The experimental class demonstrated a much superior enhancement in students' computational thinking ability compared to the control class. The results of this study align with those of Supiarmo et al. [42] indicating that the application of realistic mathematics significantly enhances students' computational thinking abilities, as evidenced by the higher N-Gain value in the experimental group (0.7) compared to the control group (0.5), derived from experimental research involving 22 students in the experimental group and 24 in the control group. Moreover, the findings of this study align with those of Ahmad et al. [43], demonstrating that the implementation of realistic mathematics education rooted in Mandailing culture, supported by Technological Pedagogical and

Content Knowledge (TPACK), effectively enhances students' critical thinking abilities in mathematics. Additionally, the research by Ritonga et al. [12] indicated that students engaged in Realistic Mathematics learning based on Mandailing culture, utilizing a Deep Learning approach, exhibited a notable improvement in logical reasoning skills relative to the control group.

DISCUSSION

This study's findings found that the application of IoT-assisted Mandailing Culture-Based Realistic Mathematics Learning was helpful in both learning management and enhancing students' computational thinking skills. Throughout the implementation process, educators effectively managed learning in a systematic, interactive, and student-centered manner, thereby demonstrating the model's applicability in authentic educational settings. Education should be orchestrated by positioning students at the core of the learning process, emphasizing the management of student interactions, the provision of suitable learning environments, and the delegation of responsibilities to students [44]. The efficacy is seen in the significant student engagement in watching, researching, and recreating contextual scenarios rooted in Mandailing culture, facilitated by IoT devices. Moreover, students demonstrated substantial improvements in computational thinking skills, evidenced by their improved capacity to dissect problems, identify mathematical patterns, abstract concepts, and systematically formulate algorithmic processes. The integration of cultural context and IoT devices fosters a genuine and meaningful learning experience [45], hence promoting active engagement and the organic development of students' computational thinking skills [46]. Consequently, the findings validated the fact that the integration of local cultural context and IoT-based technology enhances student engagement and fortifies the higher-order cognitive processes fundamental to computational thinking. The established learning paradigm is both pedagogically robust and cognitively effective in cultivating 21st-century mathematics skills.

The efficacy of the IoT-assisted Mandailing Culture-Based Realistic Mathematics Learning Model was further discussed through an analysis of four principal indicators of computational thinking skills: decomposition, pattern identification, algorithmic thinking, and generalization/abstraction. The findings indicated that the decomposition indicator underwent the most substantial enhancement. The cultural backdrop and the application of IoT necessitated that students decomposed intricate difficulties into basic elements to comprehend the relationships among components both concretely and methodically [47]. Students demonstrated the capacity to deconstruct mathematical difficulties within the Mandailing cultural framework, exemplified by calculations pertaining to the gordang sambilan (a musical instrument) or the supplies necessary for traditional activities, into smaller, more manageable elements. The deconstruction process became more intuitive as the cultural context offered concrete, easily visible representations [48], allowing students to engage with topics that are not abstract and distant from daily experience.

Moving on, the pattern recognition indicator demonstrated significant enhancement. IoT-enabled observational activities were found to enable students to obtain real-time data from environmental or cultural events [49], such as sound intensity, repeated motions, or symbolic sequences in traditional processions. Students were instructed to identify consistent numerical patterns and mathematical correlations from this data. The recurrence of patterns inside the cultural setting enabled them to more swiftly comprehend mathematical structures, circumventing the necessity for stringent theoretical elucidations [50]. The established cultural frameworks allowed pupils to instinctively identify and employ mathematical patterns without dependence on formal abstractions. Simultaneously, the algorithmic thinking indication evolved steadily, but at a slower pace than the preceding two indicators. Formulating algorithmic steps necessitated advanced logical reasoning abilities and consistent practice [51], resulting in a gradual rather than swift progression compared to other indications. Students became capable of systematically organizing problem-solving stages via written instructions and IoT-based simulations.

The generalization/abstraction indicator showed consistent enhancement. However, it posed more difficulties for certain pupils. While students could identify patterns and develop algorithms, not all were promptly able to apply these insights to novel problem contexts [52]. Nonetheless, instructor scaffolding and group discussions facilitated the progressive construction of mathematical generalizations by the students. This indicates that abstraction is the pinnacle of computational thinking and necessitates prolonged practice [53]. It necessitates the synthesis of advanced cognitive skills, the capacity to generalize notions, and iterative practice to cultivate profound conceptual comprehension. The four markers of computational thinking were developed synergistically through the implementation of a realistic mathematics learning model grounded in Mandailing culture and supported by IoT in this study. The advancement of computational thinking encompasses deconstruction and pattern recognition as the fundamental catalysts, algorithmic thinking as the processing framework, and generalization/abstraction as the sophisticated cognitive result [54]. Consequently, this model is not only broadly effective but has also demonstrated the capacity to cultivate computational thinking skills in a systematic and realistic fashion, consistent with the attributes of students' cognitive growth.

The Mandailing cultural setting significantly enhanced students' quantitative computational thinking skills through its values, interaction patterns, and daily activities incorporated in the learning process. The cultural background in this study served as a cognitive link between real-life experiences and mathematical abstractions [55]. Cultural components, including weaving patterns, the architecture of the Bagas Godang traditional house, the Marsiadapari rice cultivation system, and the Dalihan natolu philosophy, could inherently embody concepts of decomposition, pattern recognition, social algorithms, and rule generalization, which are subsequently articulated in mathematical terms via a pragmatic approach. The use of local culture in learning makes students better understand abstract concepts and apply them in everyday life [56]. This method enhanced the significance of learning while promoting students' emotional involvement and cultural identity, hence expediting the assimilation of computational concepts [57]. Consequently, culture serves as a structural framework for systematic reasoning, allowing pupils to develop cognitive algorithms based on familiar customary practices [58]. These findings affirm that enhancing computational thinking in mathematics education can develop organically through a pedagogically and reflectively crafted local cultural framework. The use of the Internet of Things (IoT) in Realistic Mathematics Learning rooted in Mandailing culture has demonstrated a substantial impact on enhancing the process of genuine and contextual mathematical discovery. The implementation of IoT devices as Learning Management Systems facilitates students' reconstruction of mathematical concepts through investigative procedures grounded in real experiences [59]. Consequently, the Internet of Things serves not merely as a technological instrument but also as a pedagogical catalyst that enhances the fundamental attributes of Realistic Mathematics Education: guided reinvention, progressive mathematization, and contextually-based engagement. These findings further validate that the interplay between local culture and contemporary technology can establish a learning environment that is more inclusive, flexible, and pertinent to the requirements of 21st-century competencies.

The results of this study correspond with several international and national research efforts that validate the efficacy of context-based learning methodologies in fostering higher-order thinking skills, especially computational thinking. This study's global findings correspond with prior research [60], indicating that the use of interactive technology in education can markedly enhance students' skills in deconstruction, pattern recognition, algorithm development, and abstraction [59; 61; 62]. Previous studies [55; 63], have corroborated that Realistic Mathematics Education, grounded in local wisdom, enhances cognitive engagement and the interrelation of mathematical concepts with students' cultural experiences. Building upon these studies, the current research offers a more sophisticated contribution than prior research by contextualizing learning within local Mandailing culture while concurrently integrating IoT technology, creating a synergy between cultural and digital dimensions. This hybrid methodology has not been extensively utilized in prior research at either the national or worldwide levels, rendering this study a complement and extension of the contextual mathematics learning paradigm that is moving towards a more authentic, adaptable, and data-driven strategy for 21st-century education. This study's findings also have significant theoretical implications for the advancement of mathematics learning models in the context of digital transformation. These findings conceptually affirm that the integration of Realistic Mathematics Education (RME) and computational thinking is both compatible and mutually reinforcing in fostering meaningful knowledge development. The synergy between the Mandailing cultural setting and IoT devices illustrates that the interpretation of mathematics rooted in local values may harmoniously coexist with contemporary technology, hence contesting the entrenched belief that local wisdom and digitalization are distinct domains.

CONCLUSION

This study has proven that the IoT-assisted Mandailing Culture-Based Realistic Mathematics Learning model is effective in improving students' mathematical computational thinking skills. This effectiveness is reflected in two main findings: first, learning management ran optimally with high student involvement in exploratory activities based on local culture; second, the achievement of computational thinking skills, including decomposition, pattern recognition, algorithmic thinking, and abstraction, showed a significant increase in all measured indicators. The integration of Mandailing culture in this study not only functioned as an illustrative context but also acted as cognitive scaffolding that connected empirical experiences with computational thinking structures, while IoT support strengthened the process of visualization and concept validation in real-time. The theoretical contribution of this study lies in strengthening the paradigm that culture and technology are not separate entities, as both can collaborate synergistically to build a more humanistic and futuristic mathematics learning model.

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