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Cultural Values in the Classroom: The Role of the Nan Sakato Principle in Developing Mathematical Communication

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Abstract

This study developed a cooperative learning model integrating Numbered Heads Together (NHT) with the Minangkabau Nan Sakato principle to strengthen students' mathematical communication. Using a research-and-development design based on the Plomp development framework, the study involved 67 Grade 10 students from two public senior high schools in West Sumatra, Indonesia. The developed model was evaluated in terms of validity, practicality, and effectiveness through expert validation, classroom implementation, and mathematical communication assessment. The intervention was conducted over eight meetings, focusing initially on systems of linear equations in three variables and subsequently on related linear-inequality tasks to examine the consistency of communication practices. The results showed that the model met validity and practicality criteria and produced moderate improvements in students' mathematical communication, with mean N-gain scores of 0.47 and 0.44 across the two classes. Significant differences between pretest and posttest scores were also observed. Beyond demonstrating instructional effectiveness, the findings reveal that Nan Sakato values can function as culturally grounded interaction norms within cooperative learning. These values support deliberation, solidarity, responsibility, and adherence to shared expectations, thereby shaping students' participation and mathematical discourse. The study contributes a transferable design principle for culturally responsive mathematics education by demonstrating that local cultural values can be operationalized not only as contextual resources but also as mechanisms for organizing disciplinary interaction.

Keywords: Numbered Heads Together, Nan Sakato, mathematical communication, cooperative learning, culturally responsive mathematics education, indigenous knowledge.

Introduction

Mathematical communication is a fundamental component of mathematical competence because students are expected not only to obtain correct answers but also to represent ideas, explain reasoning, justify procedures, and respond to others' mathematical thinking (Kilpatrick et al., 2001; NCTM, 2000; Schoenfeld, 2014). From a sociocultural perspective, these practices are developed through participation in socially mediated activity and classroom discourse rather than through individual cognition alone (Sfard, 2019; Vygotsky, 1987; Yackel & Cobb, 1996). Accordingly, the quality of interaction in the classroom is central to the development of mathematical meaning and communication.

Despite its importance, mathematical communication remains difficult for many students. International research has documented persistent challenges in expressing mathematical ideas clearly, coordinating multiple representations, and constructing logically organized arguments (Lithner, 2017; Planas, 2018). In Indonesia, PISA 2022 results similarly point to difficulties in mathematical reasoning and in formulating and interpreting solutions in non-routine contexts (OECD, 2023). Classroom-based research has also reported difficulties in mathematical language and in translating contextual information into mathematical representations (Agusfianuddin et al., 2024).

A preliminary skills test involving 36 students at a public senior high school in West Sumatra, Indonesia, provided a local indication of this problem. Of the 36 students, 22 met the criterion for using mathematical symbols, terms, or notation; only 9 were able to express mathematical ideas adequately in written form; and only 3 used mathematical ideas to construct logical and convincing conjectures or arguments. These findings suggest that students' difficulties involve not only procedural knowledge but also opportunities to communicate and negotiate mathematical thinking.

Cooperative learning provides a potential structure for developing such opportunities. Numbered Heads Together (NHT) promotes participation by assigning individual responsibility within group work and requiring students to be prepared to represent collective solutions (Johnson & Johnson, 2009; Kagan & Kagan, 2009). This structure can increase participation and create repeated opportunities for students to explain and negotiate mathematical ideas.

However, the formal structure of cooperative learning does not automatically guarantee productive mathematical discourse. Unequal participation and free-rider behavior can persist when responsibility is not internalized by all group members

(Joyce, 2010). Similarly, group discussion can remain procedural or answer-oriented rather than involving explanation, justification, and conceptual negotiation when interaction is insufficiently facilitated (Gillies, 2016).

This limitation is theoretically important because mathematical learning is shaped not only by task structure but also by the social and sociomathematical norms that regulate what counts as an acceptable explanation, justification, and contribution during classroom interaction (Yackel & Cobb, 1996). Thus, improving NHT for mathematical communication requires attention to the normative quality of group interaction, not merely to the assignment of numbers or turns. Culturally responsive teaching provides a complementary perspective by treating students' cultural knowledge and values as resources for designing meaningful participation rather than as decorative contextual features (Gay, 2018). Ethnomathematics likewise emphasizes that mathematical activity is situated within cultural practices and systems of meaning (D'Ambrosio, 2001). Studies in mathematics education suggest that culturally grounded approaches can support engagement and meaningful learning, although implementation depends on how cultural resources are translated into pedagogical practice (Ramadhani et al., 2023; Sunzuma & Maharaj, 2019).

However, a critical gap remains: while cooperative-learning research commonly focuses on structural elements such as grouping and accountability, culture-based mathematics research often emphasizes cultural relevance or contextual content. Limited research has examined how indigenous values can be operationalized as interaction norms within cooperative-learning models to support specific mathematical communication practices.

The Minangkabau principle of Nan Sakato provides a relevant framework for addressing this gap. Nan Sakato consists of four interconnected values: Saiyo Sakato (deliberation and consensus), Sahino Samalu (solidarity), Anggo Tanggo (adherence to agreed norms), and Sapikue Sajinjiang (shared effort) (Amir, 2011). When translated into classroom practices, these values may complement NHT by shaping participation as shared responsibility, disagreement as deliberation, and group representation as accountability for collectively developed mathematical ideas.

This study therefore develops and evaluates an NHT learning model integrated with Nan Sakato principles using the Plomp educational design research framework. The study contributes by (1) operationalizing an indigenous cultural principle as an interaction framework within cooperative learning, (2) linking culturally grounded norms with observable indicators of mathematical communication, and (3) proposing a transferable design principle in which locally meaningful values can strengthen participation, accountability, argumentation, and consensus in mathematics learning.

Literature Review

Mathematical communication can be understood as both a cognitive accomplishment and a social-discursive practice. It includes the ability to interpret mathematical information, coordinate symbols and representations, express ideas in written or spoken form, justify claims, and respond to alternative reasoning. In sociocultural theory, higher-order thinking develops through mediated social interaction; language and shared activity therefore provide tools through which learners construct and reorganize meaning (Vygotsky, 1987). Recent mathematics-education research similarly emphasizes that learning mathematics involves participation in discourse practices such as explaining, justifying, arguing, and connecting representations rather than merely producing answers (Erath et al., 2021; Prediger & Neugebauer, 2021). Thus, mathematical communication develops through opportunities for students to articulate, negotiate, and refine mathematical ideas (Neugebauer & Prediger, 2023).

This perspective is strengthened by the concept of sociomathematical norms. Yackel and Cobb (Yackel & Cobb, 1996) distinguish general social norms of participation from norms that are specifically mathematical, such as what counts as an acceptable explanation, a different solution, or a convincing justification. Recent studies indicate that such norms influence how students interpret legitimate participation and mathematical authority (Lim et al., 2023). Therefore, mathematical communication, particularly argumentation, requires students to coordinate claims, reasons, evidence, and mathematical warrants through interaction (Reuter, 2023). Dialogic work is productive when classroom interaction moves beyond exchanging answers toward collective examination of mathematical meaning (Mercer & Littleton, 2007; Sfard, 2019).

Cooperative learning provides a structural basis for such interaction by combining positive interdependence, face-to-face interaction, and individual accountability (Johnson & Johnson, 2008; Slavin, 1980). NHT operationalizes accountability through numbered group members and random selection of a representative. Nevertheless, structural accountability alone does not determine the quality of discourse. Research on language-responsive instruction indicates that students need repeated opportunities to explain, justify, and refine mathematical ideas, supported by interactional routines and teacher moves that sustain discursive demand. Without norms that distribute participation and require explanation, students may comply with cooperative procedures while mathematical reasoning remains concentrated in a small number of group members (Gillies, 2016). Therefore, effective cooperative learning depends on the alignment between instructional structures and norms that regulate mathematical interaction. Therefore, effective cooperative learning depends on the alignment between instructional structures and norms that regulate mathematical interaction (Cohen, 1994).

This provides a basis for integrating a culturally grounded normative system with NHT: the cooperative structure determines who is responsible for participating, while the cultural norms can shape how students deliberate, support one another, follow agreed procedures, and construct a group position.

Culturally responsive teaching views culture as a resource that can influence communication, relationships, participation, identity, and the organization of learning. Contemporary mathematics-education scholarship further argues that culturally responsive or culturally sustaining pedagogy should be visible in the design of mathematical participation, not treated as an optional contextual addition (Marshall, 2023; Thomas et al., 2024).Ethnomathematics similarly challenges the assumption that mathematical activity is culturally neutral and emphasizes connections between mathematical ideas and culturally situated ways of knowing and acting (D'Ambrosio, 2001). Studies from different cultural settings show that local knowledge, language, values, and practices can be legitimate resources for mathematics curriculum and pedagogy (Lidinillah et al., 2022; Acharya et al., 2021). For the present study, the relevance of culture lies less in embedding local objects in mathematical tasks than in using culturally meaningful values to regulate the social processes through which students engage with mathematical ideas.

Nan Sakato is especially relevant because its four values correspond to recurring challenges in cooperative learning. Saiyo Sakato frames disagreement as deliberation oriented toward an agreed position; Sahino Samalu emphasizes solidarity and mutual regard; Anggo Tanggo emphasizes adherence to agreed norms and responsibilities; and Sapikue Sajinjiang emphasizes shared effort (Amir, 2011). Within NHT, these values can be translated into expectations for equitable participation, readiness to represent the group, respectful response to alternative reasoning, and collective responsibility for the mathematical quality of the group's answer.

The conceptual framework of this study links three components: NHT provides the participation structure, Nan Sakato provides culturally grounded interaction norms, and mathematical communication represents the learning outcome. Although Nan Sakato is specific to the Minangkabau context, its design logic may be transferable because other educational settings can identify locally meaningful values and align them with cooperative-learning processes and mathematical discourse practices. This perspective aligns with research emphasizing that culturally responsive mathematics pedagogy requires concrete instructional relationships and participation structures rather than treating culture as a general contextual feature (Marshall, 2023; Shultz et al., 2024; Thomas et al., 2024).

Methodology

Research Design

This study employed a research-and-development (R&D) design to develop an NHT cooperative-learning model enriched by Nan Sakato principles and to evaluate its

validity, practicality, and effectiveness for mathematical communication. Consistent with the methodological procedure reported in the parent study, development followed five Plomp phases: preliminary investigation, design, realization/construction, testing–evaluation–revision, and implementation (Plomp, 2013).

Research Procedure

The development procedure followed five sequential phases of the Plomp educational design research framework. Each phase generated evidence for developing, evaluating, and refining the NHT–Nan Sakato (NHT–NS) model, supporting materials, and research instruments.

1. Preliminary investigation.

The researcher analyzed mathematics-learning problems, relevant learning and cultural theories, curriculum requirements, and student characteristics to identify the need for a cooperative model that integrates Minangkabau values to strengthen mathematical communication.

2. Design.

The model syntax, social system, principles of reaction, supporting system, instructional effects, and accompanying effects were designed. Supporting materials included teaching modules, teacher guides, student books, and Student Worksheets (Lembar Kerja Peserta Didik [LKPD]), while research instruments included validation sheets, practicality scales, observation sheets, and a mathematical communication test.

3. Realization/construction.

The design was developed into Prototype 1 of the NHT–NS model and its supporting materials. The four NHT stages—Numbering, Questioning, Heads Together, and Answering—were integrated with Nan Sakato values to guide responsibility, deliberation, solidarity, cooperation, and mathematical presentation.

4. Testing, evaluation, and revision.

Prototype 1 and its instruments were evaluated by experts and practitioners and revised based on feedback. A small-scale trial with six Grade 10 students at a pilot school in West Sumatra was conducted to examine instrument quality, practicality, and implementation feasibility before field testing.

5. Implementation.

The revised model was implemented in two Grade 10 classes from public senior high schools in West Sumatra. During implementation, pretest–posttest data, implementation observations, and teacher and student responses were collected to evaluate the model.

Model Development

The developed model integrates the four standard NHT phases—Numbering, Questioning, Heads Together, and Answering—with explicit Nan Sakato interaction norms. During Numbering, Anggo Tanggo establishes role responsibility and compliance with agreed group procedures. During Questioning, Anggo Tanggo supports disciplined individual engagement with the mathematical problem before group discussion. During Heads Together, all four Nan Sakato values operate together: Saiyo Sakato supports deliberation and consensus, Sahino Samalu supports solidarity and mutual regard, Anggo Tanggo regulates responsibility and discussion norms, and Sapikue Sajinjiang reinforces collaborative effort. During Answering, Anggo Tanggo and Sahino Samalu frame the responsibility to present the group's agreed result clearly while respecting the collective work of the group. In this way, Nan Sakato is operationalized as a set of interaction norms rather than merely as cultural background content. The model syntax is presented in Table 1.

Table 1. Syntax of the NHT Model Based on Nan Sakato Principles

Steps of The NHT	**Teacher Learning Activities**	**Student Learning Activities**	**Nan Sakato Cultural Values.**	**Students' cognitive processes**	**Mathematical Communication Indicators**
Numbering	The teacher organizes students into groups and assigns each member a number.	Students are expected to understand that each member is responsible for following the procedures and fulfilling their assigned roles	Anggo Tanggo (adherence to norms)	Students are expected to be aware of their roles and individual readiness within the group	

Steps of The NHT	**Teacher Learning Activities**	**Student Learning Activities**	**Nan Sakato Cultural Values.**	**Students' cognitive processes**	**Mathematical Communication Indicators**
Questioning	The teacher gives mathematical problems or questions to the groups.	Students read and understand the problem individually, identify what is known and what is being asked, and prepare to contribute to the group discussion.	Anggo Tanggo (adherence to norms)	Understanding the problem individually	Understanding the problem. Identifying the given. information and what is being asked. Mathematical communication is still internal (within the student's mind).
Heads Together	The teacher circulates to monitor students' discussion activities and provides assistance when necessary.	Students discuss, exchange ideas, and work together to find solutions, strengthening their sense of responsibility.	Saiyo Sakato (deliberation and consensus), Anggo Tanggo (adherence to norms), Sahino Samalu (solidarity), Sapikue Sajinjiang (collaborative effort)	Constructing and communicating ideas collectively.	**1.** Using mathematical symbols/representations. **2.** Expressing mathematical ideas in written form and demonstrating or representing them visually. **3.** Responding to peers' opinions by presenting conjectures, reasons, or counterarguments that are appropriate and mathematically justifiable.

Steps of The NHT	Teacher Learning Activities	Student Learning Activities	Nan Sakato Cultural Values.	Students' cognitive processes	Mathematical Communication Indicators
Answering	The teacher calls a specific number, and students present the results of their discussion.	Students present the group's agreed solution when their number is called and respond to questions or feedback.	Anggo Tanggo (adherence to norms), Sahino Samalu (solidarity)	Communicating thinking results in a representative form.	1. Presenting results clearly and systematically. 2. Using appropriate mathematical language. 3. Representing the group's agreed results

Classroom Operationalization of Nan Sakato Values

To ensure replicability, Nan Sakato was operationalized as observable classroom routines rather than treated only as cultural background. At the beginning of each 2 × 45-minute meeting, the teacher formed heterogeneous groups, assigned student numbers, and emphasized Anggo Tanggo as responsibility toward agreed procedures, roles, and readiness to represent the group. During the Questioning phase, students individually identified given information, interpreted the problem, and prepared initial representations before group discussion. Meetings 1–5 focused on SPLTV, while meetings 6–8 addressed related linear-inequality tasks using the same communication indicators and NHT–NS interaction routines.

During Heads Together, students shared representations, compared solution strategies, explained reasoning, and developed group-agreed solutions. Saiyo Sakato was enacted through deliberation and consensus; Sahino Samalu through peer support and respectful listening; Sapikue Sajinjiang through shared effort and collective checking; and Anggo Tanggo through responsibility for group decisions. The teacher facilitated interaction by monitoring discussions and providing scaffolding when students encountered conceptual or procedural difficulties.

During Answering, a student selected through random numbering presented the group's solution using appropriate mathematical language and justification, while other members remained responsible for clarification and support. Thus, Nan Sakato was translated into observable practices including role responsibility, individual preparation, deliberation, peer assistance, shared solution checking, and collective accountability. These routines were maintained across the eight meetings, allowing the development of mathematical communication practices to be examined across different mathematical topics.

Participants

The field implementation involved 67 Grade 10 students from two public senior high schools in West Sumatra, Indonesia, comprising 31 students from the first school and 36 students from the second school. The instructional sequence addressed the System of Linear Equations in Three Variables (Sistem Persamaan Linear Tiga Variabel [SPLTV]) in the initial phase and related linear-inequality tasks in the subsequent phase. The same three mathematical-communication indicators and NHT–NS interaction routines were maintained throughout the intervention to examine students' communication development across different mathematical contexts. Before the field implementation, a preliminary trial was conducted with six Grade 10 students at a pilot school in West Sumatra to refine the developed model.

Instruments and Operational Definition of Mathematical Communication

Mathematical communication was operationally defined as students' ability to communicate mathematical ideas through written and representational forms. Three indicators were used: (1) using mathematical symbols, terms, or notation to represent information; (2) expressing mathematical ideas through written and visual representations; and (3) constructing convincing mathematical conjectures or arguments. These indicators guided test construction, scoring, and interpretation of student responses.

Validation sheets were used to evaluate the content and construct validity of the NHT–NS model, supporting materials, and instruments. Model validation involved three mathematics-education experts, two Minangkabau cultural experts, and two practitioners, while instrument validation involved education experts and mathematics teachers. Validator feedback was used for revision.

Practicality was assessed using four-point Likert-scale questionnaires administered to practitioners, five mathematics teachers, and six students during the small-scale trial. Students' mathematical communication was measured using a three-item essay test administered before and after implementation. The test was developed based on the three indicators and supported by a blueprint, alternative solutions, and an analytic scoring rubric.

Before field implementation, the test items were empirically examined in the small-scale trial. The instrument demonstrated acceptable validity and reliability, with validity coefficients ranging from 0.842 to 0.997 and an overall reliability coefficient of 0.708. Item discrimination and difficulty analyses also indicated that the test was appropriate for field implementation.

Data Analysis

Data analysis combined quantitative evaluation of model quality with descriptive interpretation of students' mathematical responses. The analyses focused on three criteria: validity, practicality, and effectiveness.

Model validity was calculated from expert and practitioner ratings using the overall mean validity index (Va). The model was considered valid when the score reached the valid category ($3 \leq Va < 4$).

Practicality was evaluated from practitioner assessments, teacher responses, and student responses using four-point Likert scales. The model was considered practical when all sources reached at least the practical category.

Effectiveness was examined through normalized gain (N-gain), paired-sample t-tests, implementation observations, and user responses. N-gain values were interpreted as low ($g < 0.30$), medium ($0.30 \leq g \leq 0.70$), or high ($g > 0.70$). The effectiveness criterion required an average N-gain in at least the medium category and at least 80% of students achieving medium-or-higher N-gain.

Students' written test responses and group LKPD work were analyzed descriptively using the predetermined mathematical communication rubric. Response patterns and indicator scores were compared across meetings to identify developmental trends and persistent difficulties. Selected responses were used only as illustrative evidence of how students represented and communicated mathematical ideas. Supplementary interviews were interpreted descriptively to clarify difficulties observed in written responses and were not subjected to thematic coding.

Results

Validity of the Model

The NHT-NS model met the study's validity criterion. Content validation by three mathematics-education experts, two Minangkabau cultural experts, and two practitioners produced Va = 3.688, while construct validation produced Va = 3.480. Both values fall within the study's valid interval ($3 \leq Va < 4$). The validators nevertheless recommended revisions to improve coherence among learning components, clarify links between Nan Sakato values and model components, and refine implementation guidance before field testing.

The measurement instrument also demonstrated adequate quality for use in the field implementation. All three mathematical communication items met the study's validity criterion ($r = 0.845$, 0.842, and 0.997), the three-item test had reliability $r11 = 0.708$, and all discrimination indices were categorized as good (0.311–0.388). The set also intentionally included easy, medium, and difficult items, supporting coverage of different levels of task difficulty.

Practicality of the Model

Practicality was supported consistently across practitioner, teacher, and student assessments. The practitioner table reports an overall mean of 3.32, the five-teacher response scale yielded a total mean of 3.50, and the six-student response scale yielded a total mean of 3.45. These values fall within the $3 \leq PR < 4$ range interpreted in the study as good/practical. Qualitative feedback indicated that the model was

understandable and usable, while the main implementation concern concerned time allocation for group discussion; this feedback was used to refine the learning procedure before field implementation.

Effectiveness of the Model

a. Mean N-gain of Mathematical Communication Skills

Effectiveness was examined from pretest–posttest improvement in mathematical communication using N-gain and paired-sample t-tests, supported by implementation observations and user responses. Tables 2 and 3 summarize the N-gain distributions for the two field-implementation classes.

Table 2. N-gain for the First School (n = 31)

N-gain Category	Number of Students
High	1
Medium	27
Low	3
Mean N-gain	0.47

Table 3. N-gain for the Second School (n = 36)

N-gain Category	Number of Students
High	2
Medium	28
Low	6
Mean N-gain	0.44

The mean N-gain values were 0.47 for the 31-student class and 0.44 for the 36-student class, indicating medium improvement in both cohorts. In the first class, 28 of 31 students (90.3%) achieved medium-or-high N-gain, while in the second class, 30 of 36 students (83.3%) reached this category. Both classes exceeded the predefined effectiveness criterion of 80%. Furthermore, 25 students (80.6%) in the first class and 30 students (83.3%) in the second class achieved at least medium mathematical communication levels after implementation. These results indicate that the NHT–NS model met the effectiveness criteria established in the study design.

b. Paired-Sample t-Test Results

In addition to N-gain, paired-sample t-tests were used in the original analysis to examine whether the pretest–posttest changes were statistically significant. The results for both schools are shown in Tables 4 and 5.

Table 4. Paired-Sample t-Test Results for the First School

Statistic	Post-test	Pretest
Mean	62.50817	33.93683
Variance	353.0277	545.7833
Paired observations	31	31
Pearson correlation	0.9519	
Hypothesized mean difference	0	
df	30	
t statistic	19.69444	
p (one-tailed)	1.25E-18	
t critical (one-tailed)	1.699127	
p (two-tailed)	2.49E-18	
t critical (two-tailed)	2.04523	

In the first school, the mean score increased from 33.94 on the pretest to 62.51 on the posttest. The paired-sample test indicated a statistically significant difference, $t(31) = 19.69$, $p < .001$ (two-tailed).

Table 5. Paired-Sample t-Test Results for the Second School

Statistic	Post-test	Pretest
Mean	62.818	37.26929
Variance	354.7773	458.1421
Paired observations	36	36
Pearson correlation	0.931505	
Hypothesized mean difference	0	
df	35	
t statistic	19.22259	
p (one-tailed)	3.85E-20	
t critical (one-tailed)	1.690924	
p (two-tailed)	7.7E-20	
t critical (two-tailed)	2.032245	

In the second school, the mean score increased from 37.27 on the pretest to 62.82 on the posttest. The paired-sample test indicated a statistically significant difference, $t(36) = 19.22$, $p < .001$ (two-tailed).

c. Development of Mathematical Communication by Indicator

The indicator-based analysis of group LKPD work in the 31-student field class showed that mathematical communication developed progressively across the intervention. Symbolic representation developed earlier than written explanation and

mathematical argumentation. On LKPD-1, Indicator 1 (using mathematical symbols, terms, or notation to represent information) reached the maximum weighted score and met the mastery criterion, whereas Indicator 2 (written expression of mathematical ideas) and Indicator 3 (constructing mathematical arguments) remained below their respective thresholds. This pattern suggests that students were initially more capable of translating information into mathematical forms than explaining and justifying their reasoning.

Indicator 2 improved rapidly after repeated participation in Heads Together activities. On LKPD-2 and LKPD-3, students exceeded the mastery criterion as they engaged in writing mathematical procedures, comparing representations, and explaining solution strategies. These findings indicate that structured opportunities for discussion and explanation supported students' ability to communicate mathematical ideas in written forms.

Indicator 3 developed more gradually and represented the most demanding aspect of mathematical communication. Although argumentation remained below mastery in the early SPLTV tasks, students showed continuous improvement through repeated opportunities to justify solutions, respond to peers, and negotiate mathematical meanings. By LKPD-5, all groups achieved mastery in written explanation and argumentation, indicating a progression from basic representation toward more complete mathematical reasoning.

The same communication pattern remained evident when the mathematical context shifted to linear inequalities in meetings 6–8. Students maintained high performance in written representation and argumentation, although some scaffolding was initially required for the new topic. By LKPD-8, all three indicators reached high performance levels, with students successfully representing information, developing mathematical models, and supporting conclusions with appropriate arguments. These findings indicate consistency of the communication practices developed through NHT–Nan Sakato across related algebraic topics, rather than evidence of a separate formal transfer effect.

d. Illustrative Analysis of a Student Mathematical Communication Response

To illustrate the application of the operational indicators, an example of a student response to a system-of-linear-equations contextual task is presented. The task required students to represent unknown quantities using mathematical symbols and formulate a system of linear equations.

Student's Response:

x = price of a comic

y = price of a notebook

z = price of a marker

Model:

3x	+	2y	+	2z	=	49,000
2x	+	2y	+	4z	=	48,000

x + 3y + 3z = 35,000

The response demonstrates two aspects of mathematical communication. First, the student successfully identified relevant quantities and represented them using appropriate mathematical symbols, indicating competence in mathematical representation. Second, the student translated contextual information into a complete system of linear equations, demonstrating the ability to express mathematical ideas through written representations. This example illustrates how students' responses were evaluated against the operational indicators. However, it is presented only as an illustration of scoring interpretation and does not represent a separate qualitative analysis of the entire sample.

Discussion

This study advances culturally grounded mathematics education by providing evidence that an indigenous value system can be transformed from a contextual resource into an interactional design framework within cooperative learning. The NHT–Nan Sakato model fulfilled the criteria of validity, practicality, and effectiveness, with both implementation classes exceeding the predefined benchmark of 80% of students achieving medium-or-higher N-gain. However, the moderate gains (0.47 and 0.44) indicate that the contribution should be interpreted as evidence of meaningful improvement under authentic classroom conditions rather than superiority over alternative instructional approaches.

The role of Nan Sakato becomes evident through its relationship with mathematical activity. Mathematics classrooms are social environments where students negotiate meanings, evaluate explanations, and determine acceptable reasoning. Consistent with Dreher et al. (2021), which highlights the influence of culturally situated expectations on mathematical practices, this study shows that Nan Sakato provides explicit norms for collaboration. Saiyo Sakato supports deliberation toward agreement, Sahino Samalu promotes mutual support, Sapikue Sajinjiang strengthens shared responsibility, and Anggo Tanggo reinforces commitment to agreed procedures. Therefore, Nan Sakato contributes not only to cooperation but also to the interactional conditions supporting mathematical reasoning.

The development pattern of students' mathematical communication further explains the contribution of the model. Students initially demonstrated stronger performance in symbolic representation, whereas written explanation and argumentation developed more gradually. This indicates that mathematical communication develops progressively through sustained opportunities to explain, negotiate, and justify ideas. Symbolic representation may emerge earlier because it involves translating information into mathematical forms, while explanation and argumentation require more complex processes of organizing reasoning, providing

justification, and responding to alternative perspectives. Within NHT–Nan Sakato, repeated deliberation through Saiyo Sakato, peer support through Sahino Samalu, and shared responsibility through Sapikue Sajinjiang may facilitate students' movement from representing information toward constructing mathematical arguments.

This interpretation is consistent with research showing that mathematical language develops through opportunities for meaningful participation, explanation, and refinement of reason (Erath et al., 2021; Prediger & Neugebauer, 2021). The present study extends this perspective by showing that culturally grounded interaction norms can provide social conditions that support the development of mathematical communication.

The consistency of communication performance from SPLTV activities to linear-inequality tasks suggests that the interaction routines established through NHT–Nan Sakato were not restricted to a single mathematical topic. However, this finding should be interpreted as consistency within one intervention sequence rather than evidence of formal transfer across independent contexts.

Beyond classroom outcomes, this study contributes a transferable design principle for culturally responsive mathematics pedagogy. Rather than treating culture only as a source of examples or representations, the NHT–Nan Sakato model demonstrates how cultural values can be mapped onto instructional functions such as accountability, deliberation, peer support, and collective reasoning (Suh & Calabrese, 2025).

The international relevance lies not in adopting Minangkabau values directly, but in identifying locally meaningful principles and aligning them with disciplinary learning goals. This perspective supports culturally grounded mathematics instruction that recognizes diverse knowledge systems while maintaining pedagogical purpose.

Conclusion

This study developed an NHT cooperative-learning model in which the Minangkabau Nan Sakato principle was operationalized as interaction norms for mathematical communication. The model fulfilled the criteria of validity, practicality, and effectiveness, with both field classes exceeding the predefined effectiveness criterion. The theoretical contribution of this study is that cooperative-learning design can be strengthened through the integration of instructional structures and socio-cultural norms. NHT provides participation accountability, while Nan Sakato contributes culturally meaningful norms of deliberation, consensus, solidarity, and shared responsibility. This demonstrates that culture can shape not only the context of mathematical tasks but also the quality of classroom interaction.

The broader contribution is a transferable design principle in which locally meaningful values can be identified and aligned with disciplinary communication practices in cooperative learning. Several limitations should be acknowledged. The

findings are limited to a specific Minangkabau cultural context, purposively selected intact classes, a one-group pretest–posttest design, and an eight-meeting intervention period. Therefore, the results should be interpreted as evidence of improvement within the implemented context rather than definitive evidence of causal superiority or long-term effectiveness. Future research should employ comparative designs, examine implementation across diverse cultural settings, and investigate the long-term development and cross-context applicability of culturally grounded interaction frameworks.

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