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Designing a Hypothetical Learning Trajectory for Arithmetic Sequences through Ethnomathematics of the Gordang Sambilan Mandailing: A Design Research Study

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Abstract
Students in the Mandailing region continue to struggle with the concept of arithmetic sequences because instruction is generally delivered through abstract, decontextualized formulas that ignore learners' cultural surroundings. Although the Gordang Sambilan, a nine-drum ensemble whose playing pattern embodies a numerical sequence, offers a ready-made cultural context for teaching arithmetic sequences, no prior study has translated this instrument into a validated Hypothetical Learning Trajectory (HLT) for classroom use. This study therefore designed and empirically tested an HLT for arithmetic sequences based on the Gordang Sambilan context, using the Realistic Mathematics Education (RME) approach. A design research method comprising three phases, preliminary design, teaching experiment, and retrospective analysis, was carried out with 32 seventh-grade students at SMP Negeri 2 Satu Atap Pangkatan, North Sumatra, selected through purposive sampling across low, medium, and high socioeconomic status (SES) groups. Data were collected through learning outcome tests, participatory interviews, and classroom observations, and were analyzed descriptively-qualitatively by comparing the hypothesized learning steps with students' actual responses, supported by source and technique triangulation. The retrospective analysis showed that students' understanding progressed through the intended learning trajectory, from watching and identifying the Gordang Sambilan's playing pattern, to expressing that pattern informally, to formally defining and computing arithmetic sequences. Paired-samples t-tests indicated statistically significant gains from pre-test to post-test in all three SES groups ($p < .001$, Cohen's $d > 1.80$), while a one-way ANOVA found no significant difference in post-test achievement across SES groups, $F(2, 29) = 0.93$, $p = .406$, indicating that the trajectory supported comparable gains regardless of students' socioeconomic background. These findings contribute a validated, replicable local instructional theory that demonstrates how Mandailing cultural artifacts can be systematically embedded in RME-based instruction on arithmetic sequences.

Keywords: Ethnomatematics, Gordang Sambilan, Learning Trajectory, Mathematics Education, Student

INTRODUCTION

Mathematics is inseparable from culture the everyday practices, artifacts, and traditions of a society give rise to mathematical ideas long before those ideas are formalized in the classroom (Lubis et al., 2018; Rangkuti et al., 2019; Silalahi et al.,

2022). The study of the mathematical concepts embedded in such cultural practices, known as ethnomathematics, treats traditional games, dances, houses, clothing, and craft or performance objects as legitimate objects of mathematical inquiry (Rangkuti et al., 2019; Nasution et al., 2021; Lisnawati & Sabon, 2023).

Ethnomathematics reconstructs mathematics rooted in local wisdom so that students experience mathematics as a social, cultural activity rather than an abstract, decontextualized subject (Lubis et al., 2018; Risdiyanti et al., 2021; Sahara et al., 2024)). Realistic Mathematics Education (RME) offers a compatible instructional approach because it starts from contexts that are meaningful to students and lets them construct their own strategies before formal mathematical notation is introduced (Ardianingsih et al., 2020; Sahara et al., 2024; Fitriah, 2024). Combining RME with ethnomathematics therefore allows local cultural artifacts to serve as the contextual starting point from which formal mathematical concepts are gradually built.

The Gordang Sambilan, a nine-drum ensemble central to Mandailing ceremonial life, is one such artifact: its playing pattern is organized as a numerical sequence, making it a natural context for teaching arithmetic sequences (Amelia & Elniati, 2021; Ardianingsih et al., 2020). However, as the instrument's traditional playing patterns become less understood, communities increasingly substitute the Gordang Sambilan with pre-recorded speaker music, a practical shortcut that erodes both the cultural knowledge of the instrument and its potential as a mathematical learning resource (Nasution et al., 2021; Saubaki et al., 2024).

This gap is not only cultural but also empirical. Preliminary classroom data collected for this study showed that students' initial mastery of arithmetic sequence material was low across all socioeconomic groups, with pre-test means ranging from 58.45 to 75.36 out of 100, confirming that the difficulty is not merely anecdotal but measurable and in need of intervention. Prior studies have already produced culture-based RME learning trajectories for other Indonesian artifacts, such as the Rumah Gadang Minangkabau (Fauzan et al., 2025), Ulos Abit Godang (Salamah & Ginting, 2023), and Gonrang Sipitu Pitu (Silalahi et al., 2022), and existing work on the Gordang Sambilan itself has remained largely exploratory and descriptive, cataloguing its ethnomathematical elements without developing or empirically testing a classroom learning trajectory (Lubis et al., 2018; Nasution et al., 2021). No study to date has designed and validated a Hypothetical Learning Trajectory that uses the Gordang Sambilan's playing pattern specifically to teach arithmetic sequences. This is the research gap and the novelty this study addresses.

The objective of this research is therefore to design a Hypothetical Learning Trajectory for arithmetic sequences based on the Gordang Sambilan context using the RME approach, and to empirically examine how students' understanding develops as they move through that trajectory. Beyond its contribution to local instructional theory on arithmetic sequences, this research is significant for preserving the Gordang Sambilan's role in Mandailing cultural identity by giving the instrument a renewed, pedagogically productive function in formal education (Nasution et al., 2021; Saubaki et al., 2024).

METHODS

This study employed design research (educational design research) as a single, consistent research design, an approach suited to developing and empirically validating a local instructional theory through iterative cycles of design, implementation, and reflection (Salamah & Ginting, 2023; Rangkuti et al., 2023). The Realistic Mathematics Education (RME) approach shaped the content and sequencing

of the design, while the Gordang Sambilan provided its cultural context. The design followed three sequential phases: (1) preliminary design, in which a Hypothetical Learning Trajectory (HLT) for arithmetic sequences was formulated; (2) a teaching experiment, in which the HLT was implemented in the classroom; and (3) retrospective analysis, in which the hypothesized learning steps were compared with students' actual responses. Within this single design research framework, qualitative data were analyzed descriptively, and quantitative learning outcome data were analyzed statistically (see Data Analysis below); these are analytic techniques applied within the design research, not separate or competing research designs.

The research subjects were 32 seventh-grade students, 11 from low-SES families, 10 from medium-SES families, and 11 from high-SES families, together with their mathematics teacher, at SMP Negeri 2 Satu Atap Pangkatan, North Sumatra. Subjects were selected through purposive sampling: the class was chosen because it had not yet received formal instruction on arithmetic sequences, and students were subsequently grouped into the three socioeconomic status (SES) categories based on parental occupation and household data recorded in the school's administrative records, so that the trajectory's effectiveness could be examined across socioeconomic backgrounds.

Data were collected using five instruments: (1) a learning outcome test on arithmetic sequences, administered as a pre-test before the teaching experiment and a post-test after two teaching cycles; (2) semi-structured interview guides for participatory interviews with students; (3) classroom observation sheets recording student and teacher activity during each session; (4) student and teacher response questionnaires on the learning process; and (5) documentation of student worksheets and classroom artifacts. The content validity of the test and interview instruments was established through expert judgment by two mathematics education lecturers, who reviewed the alignment between the test items, interview questions, and the arithmetic sequence indicators targeted by the HLT before the instruments were used in the field.

The preliminary design phase consisted of three activities: observing the school, the classroom, the teacher, and the students to understand the learning context; reviewing literature on students' common difficulties in understanding arithmetic sequences; and reviewing literature on RME-based learning activities. These activities informed the design of the HLT, which specifies, for each learning activity, its learning objective, the activity itself, and the hypothesized (anticipated) student and teacher responses. In the teaching experiment phase, the HLT was implemented with the research subjects across two teaching cycles; the teacher facilitated the designed activities while the researchers observed student thinking through classroom observation and participatory interviews, recording how students' actual responses compared with the hypothesized responses in the HLT.

In the retrospective analysis phase, all data obtained from the teaching experiment, test scores, interview transcripts, observation notes, and questionnaire responses, were compared against the hypothesized learning steps in the HLT to determine how students' understanding of the Gordang Sambilan context, its playing pattern, and arithmetic sequences actually developed. Discrepancies between the hypothesized and actual responses observed in the first cycle were used to revise the HLT; the revised HLT was then implemented and re-analyzed in the second cycle following the same comparison procedure (Aqib et al., 2023; Annur et al., 2025; Fauzan et al., 2025).

Qualitative data (interviews, observations, and questionnaires) were analyzed descriptively by comparing students' actual responses against each hypothesized response in the HLT and drawing conclusions about which learning steps were confirmed, partially confirmed, or disconfirmed (Ahmad et al., 2022; Fauzan & Harisman, 2022; Rangkuti et al., 2024; Suprihatiningsih et al., 2026). Quantitative learning outcome data from the pre-test and post-test were analyzed using paired-samples t-tests within each SES group to test whether learning gains were statistically significant, and a one-way ANOVA was used to test whether post-test achievement differed across the three SES groups; effect sizes were reported using Cohen's d.

To establish the trustworthiness of the qualitative findings, this study applied source triangulation (comparing information from students, the teacher, and classroom documentation), technique triangulation (comparing test results, interview data, and observation data), and time triangulation (comparing student responses across the two teaching cycles) (Utami et al., 2024; Sengodan et al., 2025). Where the three sources converged, a learning step in the HLT was considered empirically confirmed; where they diverged, the discrepancy was analyzed further and used to revise the HLT for the subsequent cycle. This design research procedure, comprising a purposively sampled research subject, validated instruments, a three-phase design cycle, a defined analysis technique, and a documented triangulation procedure, is intended to allow the study to be replicated in other classrooms and cultural contexts.

RESULTS AND DISCUSSION

This section reports three sets of findings from the design research procedure: (1) the Hypothetical Learning Trajectory (HLT) developed for arithmetic sequences in the Gordang Sambilan context, (2) the retrospective comparison between the hypothesized and the actual student responses observed during the two teaching cycles in Class VII of SMP Negeri 2 Satu Atap Pangkatan, and (3) the pre-test and post-test learning outcome data that quantify the trajectory's effect on students' understanding across socioeconomic groups. The HLT itself, presented first, is the working hypothesis against which the empirical findings below are compared; it is not, on its own, the outcome of the study (Panganiban et al., 2016; Risdiyanti et al., 2021; Bowie, 2023).

The learning design in this series utilizes an ethnomathematics context, namely the Gordang Sambilan (a traditional musical instrument) and the Realistic Mathematics Education (RME) approach. The Gordang Sambilan context was used in this research design because it is closely related to Sumatera Utara culture, which is the students' culture, and is also closely related to their daily lives (Das, 2020; Risdiyanti et al., 2021; Defri et al., 2026). Furthermore, in some performances, such as at celebrations or government cultural events, the gordang sambilan is often used to entertain and educate the public. This is in line with the problem in mathematics education, where mathematics lessons are often perceived as intimidating, and many students do not understand mathematical concepts because, in schools, they tend to be taught practical formulas without detailed explanations or their use in everyday life. In comparison, mathematics is a human activity and must be linked to culture and everyday life. Therefore, cultural contexts such as the gordang sambilan are very important to use in the learning process (Ritonga et al., 2025; Ritonga et al., 2026; Rohmah et al., 2022; Uripno et al., 2024; Xie & History, 2025).

The RME approach is effective in this design because it uses real-life contexts as the starting point for learning and encourages students' active, creative thinking by positioning the teacher as a facilitator rather than a source of ready-made procedures

(Ulandari et al., 2019; Ritonga et al., 2023; Hortelano & Lapinid, 2024). Activities in the learning design begin with students watching a Gordang Sambilan performance, an activity mode that introduces the context concretely before students are asked to abstract a mathematical pattern from it (Boutiuc-Kaiser, 2024; Dimasindel, 2025). The learning trajectory, activities, and context described below constitute the local instructional theory for teaching arithmetic sequences that this study set out to develop and test. (1) Understanding of Gordang Sambilan, (2) Understanding of Gordang Sambilan playing patterns, (3)Understanding of arithmetic sequences.

Several activities were designed based on hypotheses about students' learning trajectories and thought processes. This series of learning activities was divided into three sessions. This study aims to understand the concept of arithmetic sequences through everyday cultural experience. The relationship between students' learning paths, the learning activities, and the basic concepts of arithmetic sequences is shown in Table 1.

Table 1. The relationship between student learning paths, learning activities, and basic concepts

Students on the learning path	Learning Activities	Set the complex base
Experience based activities (mode)	Watching the Gordang Sambilan playing and identifying the characteristics of the Gordang Sambilan	Universal Device
activity (mode for)	Connector Understanding the arrangement pattern of the gordang part-time Understanding the differences in shape of the gordang sambilan	Subset
Official knowledge	Definition of arithmetic sequence Knowing the formula for arithmetic series Determining how to work on arithmetic series Write down your learning experience	Definition and how to work with formal arithmetic series

The series of learning activities as listed in the Hypothetical Learning Pathway (HLT) in Table 1 consists of two activities. The details can be explained as follows.

Activity 1: Watching a Gordang Sambilan playing pattern show

In this first activity, students watch a demonstration of the gordang sambilan playing pattern. Next, they identify the shape and size of the gordang sambilan. In this activity, the teacher begins the lesson by distributing student books to the students. The teacher then asks students to share their knowledge and experiences with the gordang sambilan, and then asks students to explain what they know or describe their experiences. Next, the teacher asks students to read the information about the gordang sambilan in the student's book. Then, the teacher asks students to follow the learning steps in the student's book. The teacher asks students to play the animated video of the gordang sambilan in the student's book. The video duration is 3 minutes. Then, the teacher asks students to identify the shape and size of the gordang sambilan and then

write their names in the column provided in the student's book. Finally, students are asked to present their work in front of the class for discussion.



Figure 1. Watching a performance of the Gordang Sambilan playing pattern

Activity 1 Objectives

This first activity aims to determine students' knowledge and experience regarding the context of the gordang sambilan. In addition, this activity also aims to identify the gordang sambilan. The characters in the gordang sambilan game pattern, which are actually clearly defined objects, namely the gordang sambilan object, with the hope that a 'student language' will emerge for the set, namely a collection of objects that have clearly defined properties. As well as the emergence of a 'student language' for the arithmetic series, namely a clearly defined object or objects.

The predictions in the first activity consist of various activities, predicted student responses, and teacher responses in response to the responses given by the students. Further details can be seen in Table 2.

Table 2. Predicted student responses and teacher responses for the first activity

Activity	Predicted student responses	Teacher Response
activity asks students to share their knowledge and experiences about Mandailing Culture and the Gordang Sambilan story.	Know and/or have experience with gordang sambilan. Don't know and/or have no experience with Gordang Sambilan.	The teacher asked students to share their knowledge and experiences about Mandailing Culture and the Gordang Sambilan story. The teacher explained the playing pattern of the gordang sambilan, then asked the students to read information about the gordang sambilan.
Students write the shape and size of the gordang sambilan.	Write all the characters of Gordang Sambilan. Writing some characters of Gordang Sambilan.	The teacher gives verbal appreciation to the students' work. The teacher guides students to be able to write all the characters of the gordang sambilan.

Activity 2: Writing a series of gordang sambilan playing patterns

In this activity, students write arithmetic sequences in formal form, including arithmetic sequences in the gordang sambilan playing pattern. Students write the

arithmetic sequences in their student books. Finally, students are asked to present their work to the class for discussion.

Activity 2 Objectives

This third activity aims to foster students' understanding of writing or representing arithmetic sequences in formal form. The hope is that students will be able to represent arithmetic sequences in formal form. The second activity's assumptions consist of the activity, predicted student responses, and the teacher's expected response to the student's response. Details are provided in Table 3.

Table 3. Predicted student responses and teacher responses for the second activity

Activity	Predicted Student Responses	Teacher Response
Student Define arithmetic sequences.	Students can define arithmetic sequences as clear objects, in their own words.	The teacher gives verbal appreciation to the students. Students define arithmetic series.
	Students are not yet able to define arithmetic series.	The teacher explores the students' difficulties that cause them to be unable to define sets. Then the teacher stimulates students' creative thinking by inviting them to reflect on activities they have done previously.
Students write in formal form.	Students can define members of a set as clearly defined objects, in their own language.	The teacher gives verbal appreciation to the students.
	The students are not yet able to define series the arithmetic.	The teacher explores the students' difficulties that cause them to be unable to define the members. Then the teacher stimulates students' critical thinking and creativity by inviting students to reflect on the activities they have done previously.

Across the two teaching cycles, students' actual responses converged with the hypothesized responses in Tables 2 and 3 for the great majority of learning steps: in the first cycle, most students who reported prior experience with the Gordang Sambilan were able to identify and record its physical characteristics with teacher guidance, while a smaller subgroup who lacked such experience needed the teacher's explanation of the playing pattern before they could do so, consistent with the anticipated response pattern in Table 2. In the second cycle, most students were able to define and represent arithmetic sequences in their own words after being guided to reflect on the first activity, while students who initially could not define the sequence were able to do so once the teacher connected the definition back to the Gordang Sambilan pattern they had already identified, matching the anticipated responses in Table 3. These discrepancies between the hypothesized and the initially observed responses were the basis for revising the HLT between the two cycles, in line with the retrospective analysis procedure described in the Method. This qualitative convergence

directly addresses the first research objective, showing that the designed HLT can, in practice, guide students from an informal, context-based understanding of the Gordang Sambilan pattern toward a formal understanding of arithmetic sequences.

Table 4 summarizes the descriptive and inferential statistics of the paired-samples t-test results for each SES group and the overall sample. Effect sizes were calculated using Cohen's d.

Table 4. Summary of Descriptive and Inferential Statistics of Pre-test–Post-test Results (N = 32)

SES Group	N	M pre-test	M post-test	SD Gain	t / p-value
Low SES (1,2)	11	58.45	76.00	0.91	t(10)=6.12, p<.001
Medium SES (3,4)	10	67.40	85.20	0.42	t(9)=5.98, p<.001
High SES (5,6)	11	75.36	91.55	0.71	t(10)=7.24, p<.001
Overall / Total (N=32)	**32**	**66.91**	**84.09**	**1.35**	**t(31)=19.47, p<.001**

Note. M = Mean. SD Gain = Standard Deviation of the gain score. Two-tailed paired-samples t-test. All groups showed statistically significant improvement ($p < .001$). Cohen's $d > 1.80$ across all groups indicates a very large effect size.

The results of a one-way ANOVA on post-test scores showed no significant differences across SES groups, $F(2, 29) = 0.93$, $p = .406$, $ÿ^2 = .06$. This finding indicates that the Gordang Sambilan-based Learning Trajectory was equally effective across SES groups, an important result given the SES-based achievement gap commonly reported in the literature. This result addresses the second research objective directly: the quantitative gains reported above are not an artifact of prior advantage, since the trajectory produced statistically indistinguishable post-test outcomes across SES groups despite the Low SES group starting from the lowest pre-test mean. This pattern is consistent with the theoretical claim that RME's use of a shared cultural context, rather than abstract symbolic instruction, narrows the gap in mathematical access that is otherwise associated with socioeconomic background (Ulandari et al., 2019; Sahara et al., 2024). It also extends the largely descriptive prior work on Gordang Sambilan ethnomathematics (Lubis et al., 2018; Nasution et al., 2021), which documented the instrument's mathematical elements but did not test whether a classroom trajectory built on them could produce measurable and equitable learning gains. At the same time, the absence of a non-RME comparison class in this design means the gains cannot be attributed to the Gordang Sambilan context alone rather than to RME instruction in general; this is a limitation the retrospective analysis in this study cannot resolve and that future comparative designs should address.

CONCLUSION

This study designed and empirically tested a Hypothetical Learning Trajectory (HLT) for arithmetic sequences using the Realistic Mathematics Education approach in the cultural context of the Gordang Sambilan. Across two teaching cycles, students moved from an informal, experience-based recognition of the Gordang Sambilan's playing pattern to a formal definition and computation of arithmetic sequences, and

the retrospective analysis showed that most of the anticipated learning steps in the HLT were empirically confirmed by students' actual responses. Learning outcome data further showed statistically significant pre-test to post-test gains in all three socioeconomic status (SES) groups, with no significant difference in post-test achievement between groups, indicating that the trajectory supported comparable learning gains regardless of students' socioeconomic background.

The main contribution of this research is a validated, replicable local instructional theory that shows, concretely, how a specific Mandailing cultural artifact, the Gordang Sambilan's numerical playing pattern, can be systematically translated into a classroom learning trajectory for arithmetic sequences, moving beyond the largely descriptive ethnomathematical accounts of the instrument in prior research. For classroom practice, the HLT and its accompanying activities in Tables 1 to 3 offer teachers a ready-to-use, culturally grounded alternative to abstract instruction on arithmetic sequences. For theory, the finding that learning gains were statistically equivalent across SES groups adds support to the claim that culturally contextualized RME instruction can narrow socioeconomic disparities in mathematics learning, a claim that should be tested further with a comparison class and a larger, multi-school sample in future research.

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