Developing Malay Culture-Based Process-Oriented Guided Inquiry Learning (MCPOGIL) Model to Improve Mathematical Communication Skills and Student Curiosity

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Abstract

This study aimed to develop a Malay Culture-Based Process-Oriented Guided Inquiry Learning (MCPOGIL) model to improve the mathematical communication skills and curiosity of seventh-grade students. Using the Plomp development model, the study followed three phases: preliminary investigation, design and prototyping, and test, evaluation, and revision. Participants were seventh-grade students from SMPN 2 Kisaran, North Sumatra, Indonesia, during the 2023/2024 academic year. The preliminary investigation identified the need for student-centered instructional materials aligned with the Kurikulum Merdeka and integrated with Malay-Asahan cultural contexts. During the design phase, the MCPOGIL model combined the six-phase POGIL syntax with local cultural elements, particularly the Nasi Hadap-hadapan tradition. Expert validation classified the model and its supporting materials including the model book, teacher's guide, and student textbook as "Very Valid," indicating their suitability for classroom implementation. Practicality was evaluated through two iterative field trials, with revisions to language and visual design resulting in a very positive student response rate of 92.24% in the second trial. The Wilcoxon Signed-Rank Test revealed statistically significant improvements in students' mathematical communication skills and curiosity following the intervention ($p < 0.001$). The Mann-Whitney U Test further demonstrated that the revised prototype outperformed the initial version ($p < 0.001$). Spearman's rho analysis indicated no significant correlation between mathematical communication skills and curiosity ($r = -0.091$, $p = 0.610$). Overall, the MCPOGIL model proved to be a valid, practical, and effective instructional approach for enhancing both cognitive and affective learning outcomes.

Keywords: ethnomathematics, Malay-Asahan culture, mathematical communication, Plomp development model, POGIL, student curiosity

1. Introduction

The biggest problem in today's mathematics classrooms, especially in junior high school, is that most of the time, students do a poor job of communicating their mathematics, and they generally have poor learning results (Ghany et al., 2024; Maulyda et al., 2020; OECD, 2023). A preliminary needs analysis conducted at SMPN 2 Kisaran prior to the development stage confirmed that mathematics instruction remained predominantly teacher-centered, with limited opportunities for students to explain mathematical reasoning either orally or in writing. Classroom observations indicated that teachers mainly relied on direct explanation and procedural exercises, while students rarely engaged in collaborative discussion or mathematical argumentation. Informal diagnostic assessments and teacher interviews further suggested that many students experienced difficulty expressing mathematical ideas using appropriate representations and mathematical language. These findings highlight a clear need for an instructional model that simultaneously promotes mathematical communication and active student participation. Most of junior high school mathematics classes, like those at Sekolah Menengah Pertama 2 Kisaran (SMPN 2 Kisaran) in Indonesia, use traditional, teacher-centered methods that emphasize verbal explanations and include little to no student participation. These traditional methods fail to help students actively construct their own knowledge, which prevents them from communicating mathematically or solving complex math problems independently. Therefore, new ways of instructing students should be developed and implemented that will support the student-centered, constructivist approach of the *Kurikulum Merdeka* (Ardianti & Amalia, 2022; Fadillah & Yusuf, 2022; Fitra, 2023; Mardiana & Emmiyati, 2024; Rahmadayanti & Hartoyo, 2022).

One possible answer is through the Process-Oriented Guided Inquiry Learning (POGIL) model (Moog & Spencer, 2008). POGIL focuses on the student actively finding structural concepts through problem-solving. The teacher does not do the student's work; instead, the classroom shifts from the teacher to the student. This allows the student to be independent and retain the knowledge they have discovered, as they will have "owned" the principles they learned. In addition, learning is now viewed as a social and cultural process. Mental development is facilitated by the use of symbols and by social situations in which the student can utilize the context of his/her own life (Taylor, 1993).

Although numerous studies demonstrate the efficacy of constructivist teaching methods, a significant gap remains in the practical implementation of process-oriented, culturally situated inquiry models. The primary reason the standard POGIL has proven successful in increasing cognitive development is that it does so through inquiry models that are both process-oriented and culturally situated (Barthlow & Watson, 2014; Berland & McNeill, 2010; Hein, 2012; Yuliastini et al., 2018). However, when applied in their local education systems, the POGIL model often fails to be successful due to a lack of cultural relevance and detailed supporting materials. Research conducted previously, such as studies conducted by Ahmedi et al. (2023), demonstrated that many teachers who are unfamiliar with constructivist-based models experience difficulty in moving away from teacher-centered paradigms, which ultimately creates a gap between theoretical pedagogy and the actual practice of pedagogy within the classroom environment. Additionally, although general inquiry models are prevalent, very few researchers have examined integrating the Malay-Asahan cultural context into the teaching of mathematics to address the disconnect between abstract concepts and students’ lived realities. This current study bridges this gap by developing and validating a practical and effective Malay Culture-Based POGIL (MCPOGIL) model that can serve as a framework for teachers to provide students an opportunity to engage in active discovery while grounding mathematical problems within students' own cultural identity.

The purpose of the study is to improve POGIL by integrating it with Malay culture focusing on the specific cultural traditions of the Malay-Asahan community. By incorporating problems grounded in local knowledge or wisdom, such as those related to the activities of traditional markets, local community inheritance customs, and the *Nasi Hadap-hadapan* method of social interaction, mathematics becomes less abstract and more meaningful to students. Studies have demonstrated that integrating local culture into inquiry-based instruction can be a major determinant of pedagogical effectiveness (Brown, 2017; Gay, 2002; Johnson, 2011; Taira & Maunakea, 2023). This approach will provide students with a familiar stimulus from which they may construct conceptual understanding and articulate their mathematical ideas through oral and written means.

Based on the detailed Plomp development model, the MCPOGIL model was developed with an emphasis on thorough investigation prior to its development, thorough planning, and subsequent evaluation as part of the process to develop a high-quality model. In addition, the primary focus of this study was to develop a comprehensive package of support materials for this model, including model books, teaching modules, and student worksheets designed specifically for 7th-grade students. As such, the intent of the research is to create a collaborative learning environment in the classroom that allows students to engage in a “process-oriented” experience that leads to discoveries reflecting each student's cultural values and beliefs, rather than simply memorizing formulas.

Previous studies have consistently demonstrated the effectiveness of POGIL in improving students' conceptual understanding, critical thinking, collaborative learning, and mathematical problem-solving through structured inquiry and active learning (Andriani et al., 2019; Hainun et al., 2022; Muhammad & Purwanto, 2020; Nuralif, 2025; Putri et al., 2020; Rahmadhani, 2018; Yana et al., 2021; Yulia et al., 2021; Zaenal & Hermawan, 2022). Nevertheless, most of these studies have implemented POGIL as a generic instructional approach without explicitly integrating students' local cultural contexts into the inquiry process. Although a small number of studies have combined inquiry learning with local wisdom, these investigations have generally been conducted in different educational contexts, employed instructional approaches other than POGIL, or evaluated only limited aspects of instructional quality. Consequently, there remains a lack of research developing and validating a culturally responsive POGIL model specifically designed for junior high school mathematics in Indonesia that integrates Malay-Asahan cultural contexts while simultaneously examining its validity, practicality, and effectiveness in improving both mathematical communication skills and student curiosity. The present study addresses this gap through the development and empirical validation of the Malay Culture-Based Process-Oriented Guided Inquiry Learning (MCPOGIL) model using the Plomp educational design research framework.

Based on the gaps identified in previous studies and the instructional needs observed at SMPN 2 Kisaran, this study aims to develop and validate a MCPOGIL model for seventh-grade mathematics instruction. Specifically, the study seeks to: (1) develop the MCPOGIL instructional model and its supporting learning materials based on the Plomp development framework; (2) evaluate the validity and practicality of the model through expert validation and iterative field trials; and (3) examine the effectiveness of the model in improving students' mathematical communication skills and curiosity. By integrating Malay-Asahan cultural contexts into inquiry-based learning, this study is expected to provide a culturally responsive instructional model that supports the implementation of the Kurikulum Merdeka while enhancing both cognitive and affective learning outcomes.

2. Method

2.1 Research Design

This study employed R&D (Research and Development) methodological approach based on the development framework developed by Plomp, which is designed to be systematic, flexible, and iterative (Plomp & Nieveen, 2013). The Plomp model was chosen as it is particularly well-suited to developing high-quality educational interventions. The three stages of this development process were (see Figure 1): (1) The Preliminary Investigation Stage: A needs and context analysis was undertaken to determine the main problems with mathematics instruction and the opportunity for incorporating Malay-Asahan cultural aspects into the mathematics curriculum; (2) Design, Realization, and Validation Stage: The syntax and supporting materials for the Malay Culture-Based POGIL model—including the model book, teaching modules, student worksheets—were drafted and then submitted to expert validation to confirm that they had theoretical and structural integrity; and (3) Test, Evaluation, and Revision Stage: Iterative field testing (trial 1 and trial 2) was used to empirically assess the practicality and effectiveness of the model to improve students' mathematical communication skills and curiosity. As part of the continuous improvement cycle of evaluation and refinement, the study sought to develop an effective instructional model that would meet the quality criteria of validity, practicality, and effectiveness.

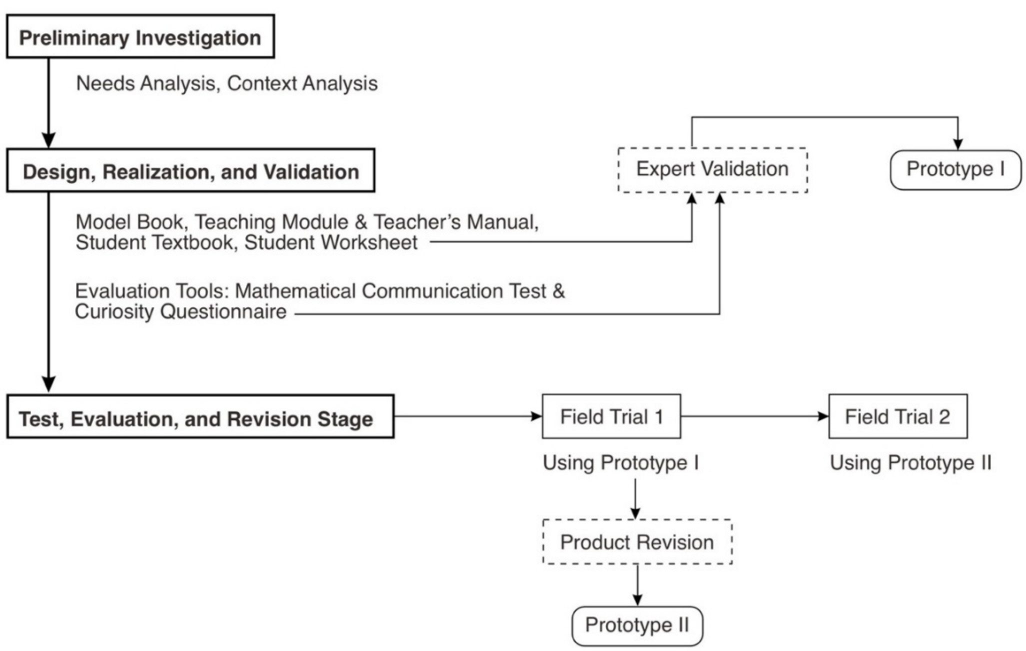

Figure 1. Research Framework

2.2 Participants and Research Setting

The participants in this study were selected using a purposive sampling technique, targeting 7th-grade students at SMPN2 Kisaran, North Sumatra, during the 2023/2024 academic year. This technique was chosen to ensure that the selected classes had similar initial mathematical abilities and were taught by the same teacher, thereby minimizing external variables. For both the first and second iterative field trials, two classes were chosen as subjects for this study: Class A (34 students) acted as the subjects for trial 1 to determine the practicality and effectiveness of the model; and Class B (34 students) was the subject for trial 2 to examine the revised version of the instructional materials. The research setting was designed to be consistent with the local Malay-Asahan culture to provide an authentic context for mathematics learning. The social and cultural backgrounds most familiar to the students, including *Nasi Hadap-hadapan* social interaction and local traditional trading practices, were used to present the mathematical problems students had to solve. The study aimed to investigate how a localized, inquiry-based approach would affect students' mathematical communication and curiosity in a real-world classroom setting.

2.3 Development of Learning Materials

The materials, as shown in Table 1, have been developed to create a comprehensive support structure for MCPOGIL model, enabling it to move from a conceptual idea to an applicable teaching practice in the classroom. The Model Book is the main guide to how the MCPOGIL model is philosophically grounded in constructivism and the six stages that comprise its syntax to encourage inquiry. For this reason, the teaching modules and the teacher's manual have been created to provide teachers with a detailed, sequential instructional path for implementing MCPOGIL model in the classroom, in line with the *Kurikulum Merdeka*. In addition, the student textbook and student worksheets have been specifically created to link mathematical problem-solving to the context of the Malay-Asahan culture, for example, the tradition of *Nasi Hadap-hadapan*. As a result, these materials will act as an intermediary between the students and the educational objectives and, therefore, help them to develop mathematical concepts through a discovery process using culturally familiar stimuli. Additionally, the assessment tools were incorporated to measure the effect of these materials on the students' ability to communicate mathematically and their curiosity, with accuracy.

Table 1. Developed Products of the Malay Culture-Based POGIL Model

No	Product Category	Developed Materials	Key Functions
1	Model Framework	Malay Culture-Based POGIL Model Book	Provides the theoretical foundation, syntax (6 phases), and operational guidelines for the model.
2	Teaching Guides	Teaching Modules and Teacher's Manual	Acts as the instructional plan for teachers, detailing how to integrate Malay culture into the inquiry process.
3	Learning Media	Student Textbook and Student Worksheets	Provides culturally-contextualized problems and structured discovery activities for students.
4	Evaluation Tools	Mathematical Communication Test and Curiosity Questionnaire	Measures the effectiveness of the model in improving target student outcomes.

2.4 Research Instruments

The measurement methods in this study were developed to assess the quality of MCPOGIL model using validity, practicality, and effectiveness as criteria. Validation sheets were given to expert reviewers to examine both the theoretical and structural merit of the instructional design supporting MCPOGIL model and, thus, determine the validity of the model and its supporting materials. Practically, the practicality of MCPOGIL model was evaluated through teacher and student response questionnaires and observation sheets to monitor classroom implementation and the degree to which teachers implemented the model as intended. The study used a mathematical communication test (adapted from (Cai et al., 1996). The mathematical communication test included essay-based problem-solving items that tested students' ability to express mathematical concepts, and the curiosity scale tested students' psychological engagement and interest in the learning process. All tools were reviewed by experts and empirically validated to ensure they were reliable and valid for data collection. The curiosity questionnaire used in this study was adapted from an instrument developed by Litman and Jimerson (2004). Although the instrument was developed more than two decades ago, it remains one of the most widely used measures of epistemic curiosity and has a strong theoretical foundation in educational research. The instrument has also demonstrated good psychometric properties across various educational contexts and has been adapted in numerous subsequent studies.

To ensure its suitability for this study, the questionnaire was culturally adapted to fit the context of mathematics learning at the junior high school level in Indonesia and reviewed by five experts in mathematics education. Several editorial adjustments were made to improve readability without altering the constructs being measured. Furthermore, the validity and reliability of the adapted questionnaire were retested during the instrument validation phase before use in the study.

Furthermore, the indicators in the questionnaire were aligned with recent research findings on curiosity in mathematics education, emphasizing students' willingness to explore mathematical ideas, ask questions, seek alternative solution strategies, and actively engage in problem-solving. This alignment ensures that the instrument remains relevant to contemporary developments in mathematics education, even though the original instrument was developed several decades ago.

2.5 Data Analysis Technique

This study evaluated the quality of the MCPOGIL model by applying the analytical techniques of validity, practicality, and effectiveness as three lenses. Validity was determined by calculating average scores across all expert validation sheets, evaluating the theoretical rationality of the model, and assessing the model's internal consistency and the accompanying material. Practicality was determined by analyzing descriptive data from teacher and student response questionnaires, measuring ease of classroom implementation, and assessing the teacher's ability to control and maintain the syntax of MCPOGIL. Effectiveness was primarily determined by two outcomes: (1) the development of mathematical communication skills and (2) student curiosity. Students' communication skills were quantitatively evaluated using N-Gain scores to compare pre- and post-test scores and determine improvement. Curiosity was also quantitatively evaluated by calculating the percentage of students who reached or exceeded a high-curiosity threshold. These results were then classified into one of four categories based on predetermined criteria to determine whether MCPOGIL model meets the standards for high-quality instructional model identification.

$$g = \frac{\text{skor postes - skor pretes}}{\text{skor maksimal ideal - skor pretes}}$$

These criteria were used to determine the effectiveness of the developed learning model in improving students' mathematical communication skills and curiosity.

Normalized Gain (g)	**Interpretation**
$g < 0.30$	Low
$0.30 \leq g \leq 0.70$	Moderate
$g > 0.70$	High

The POGIL-BBM model was implemented over four sessions with a total of eight lesson hours (8 × 40 minutes). All lessons were conducted by a seventh-grade mathematics teacher who had previously attended a two-day workshop on POGIL-BBM syntax. To maintain implementation fidelity, two observers used an observation sheet to assess the model's implementation at each session. The implementation fidelity score was calculated based on the percentage of implementation of each model's syntax.

Prior to the trial, a test of the equivalence of students' initial abilities was conducted using the pretest scores of mathematical communication abilities. The normality test was conducted using the Shapiro–Wilk test, while the homogeneity of variance was tested using the Levene Test. An Independent Sample t-test was then conducted to ensure that there was no significant difference in initial abilities between classes VII-A and VII-B ($p > 0.05$). Thus, both classes were declared equivalent and therefore suitable for use as Trial I and Trial II.

Qualitative data obtained from validator comments, observations, and teacher input were analyzed using thematic analysis techniques, including open coding, axial coding, and selective coding. The categorization results were then used as the basis for prototype revisions at each development cycle.

Content and construct validation were conducted by five validators: three Doctors of Mathematics Education with expertise in learning model development, two Doctors with expertise in educational evaluation, and experience in implementing the Independent Curriculum. All validators have experience in research and development (R&D) and have been involved in the validation process of learning tools in various previous studies.

The product validity criteria refer to the average expert validation score (Va) ≥ 4.00 (5-point Likert scale). The product is considered practical if the implementation score (IO) reaches ≥ 4.00 with teacher and student responses > 80%. Furthermore, product effectiveness is achieved if ≥ 80% of students meet the Minimum Completion Criteria (score ≥ 70), the average normalized gain is at least in the moderate category (g ≥ 0.30), and positive responses exceed 80%.

In addition to content validity, the instrument's internal reliability was tested using Cronbach's Alpha against the results of a pilot test on 34 students outside the research sample. The analysis showed that the mathematical communication skills instrument had a Cronbach's Alpha value of 0.89, while the curiosity questionnaire obtained a Cronbach's Alpha value of 0.91, indicating very high reliability.

2.6 Ethical Clearance

This research was conducted in accordance with the ethical principles of educational research involving human participants. Prior to the study, official permission was obtained from the Faculty of Teacher Training and Education, Asahan University, as well as the principals of SMP Negeri 2 Kisaran and SMP Muhammadiyah, the research locations. All research procedures were carried out in accordance with institutional provisions and regulations governing research in education. Prior to data collection, all research ethics procedures, including obtaining research permits from relevant institutions and obtaining written informed consent, were completed to ensure compliance with ethical standards for educational research.

3. Results

3.1 Preliminary Investigation Results

The results of the initial investigation phase provided an overall rationale for developing the MCPOGIL model, as presented below. The needs analysis in table 2 identified a substantial difference between the current mathematics-teaching method and the ideal standard set by the *Kurikulum Merdeka*. Student involvement was very limited due to the teacher-centered approach. Also, a notable lack of mathematical communication skills was evident among the students. As such, it was evident that a structured, student-centered instructional model and specialized learning materials were needed to support students' active construction of knowledge.

Table 2. Summary of Needs Analysis Results

Aspect	Identified Problems and Findings
Student Ability	Low mathematical communication skills and low overall student learning outcomes at Public Junior High School 2 Kisaran.
Instructional Approach	Teaching is teacher-centered and conventional, dominated by verbal concept explanation with minimal active student construction of knowledge.
Curriculum Alignment	Current practices do not yet meet the constructivist, student-centered requirements of the *Kurikulum Merdeka*.
Learning Materials	Lack of existing instructional tools and worksheets specifically designed for the POGIL model or integrated with local cultural contexts.

Table 3. Summary of Context Analysis (Student & Environment)

Context Aspect	Key Findings
Cognitive Stage	Most 7th-grade students are in the formal operational stage but still show a strong tendency for concrete thinking, requiring real-world contexts to understand abstract concepts.
Cultural Resources	The Malay-Asahan culture provides rich contexts for mathematics, including traditional market trading, inheritance distribution, and social patterns like *Nasi Hadap-hadapan*.
Social Environment	Students are not yet accustomed to collaborative inquiry-based learning or group discussion, requiring a structured social system in the learning model.
Prior Knowledge	Students have prerequisite knowledge of basic numbers and ratios from elementary school but need reinforcement to connect these to junior high school-level concepts.

The findings presented in Tables 2 and 3 were obtained through a systematic preliminary investigation involving classroom observations, semi-structured interviews, document analysis, and questionnaires administered to mathematics teachers and Grade 7 students at SMP Negeri 2 Kisaran. The preliminary investigation involved two mathematics teachers and 68 seventh-grade students. Classroom observations were conducted to identify existing instructional practices, while interviews explored teachers' perceptions regarding students' mathematical communication and curiosity. Curriculum documents and existing learning materials were also analyzed to examine their alignment with the Kurikulum Merdeka and the integration of local Malay-Asahan cultural contexts.

Additionally, the context analysisin table 3 identified the students' cognitive aspects and the underutilized resources within their environment. Although 7th-grade students have reached formal operational thinking, they continue to depend on concrete stimuli; therefore, incorporating the Malay-Asahan cultural context will be a key element in students' understanding of abstract ratio concepts.

Table 4. Literature and Concept Review Results

Component	Theoretical & Conceptual Foundation
Learning Theories	Grounded in Cognitivism, Constructivism (Piaget), Sociocultural theory (Vygotsky), Discovery learning (Bruner), and Meaningful learning (Ausubel).
POGIL Framework	Based on the POGIL cycle and the "Models of Teaching" framework by (Joyce et al., 2009).
Subject Matter	Focused on the Ratio and Proportion topic for Grade 7, organized hierarchically from basic ratio definitions to scale and inverse proportions.
Cultural Integration	Utilization of local wisdom as an authentic stimulus to trigger student curiosity and facilitate mathematical representation.

Lastly, the theoretical underpinnings of MCPOGIL model were established using the literature and concept review as seen in table 4. The literature and concept review synthesized essential learning theories, including Piaget's constructivist theory and Vygotsky's sociocultural theory, as well as the POGIL inquiry cycle. These results provide a solid foundation for the design phase, ensuring that the final model is both theoretically grounded and appropriate to students' sociocultural backgrounds.

3.2 Design and Prototyping Results

The prototype I instructional system was created at the end of the design and prototyping phase through integration of the theoretical underpinnings of POGIL with the rich sociocultural environment of the Malay-Asahan community. The prototype includes the results of the six-phase syntax and the development of support materials for both cognitive and affective growth. The structural specifications and functional roles of the prototype's materials are listed in Table 5.

Table 5. Components of the Developed Malay Culture-Based POGIL Instructional System

Category	Item	Function/Purpose
Model Guide	MCPOGIL Model Book	Provides the 6-phase syntax and theoretical basis.
Instructional Tools	Teaching Modules and Teacher's Manual	Guides the teacher in managing the inquiry process.
Learning Media	Student Textbook and Worksheets	Provides culturally-themed tasks for student discovery.
Evaluation Tools	Communication Test	Measures the cognitive skill of mathematical expression.
Evaluation Tools	Curiosity Scale	Measures the student's internal drive and engagement.

The model book and the teacher's manual provide the operational base to guide the transformation of traditional classroom instruction into guided inquiry-based instruction. Both documents provide the structure to support a consistent instructional approach. At the center of the student's experience is the student textbook and worksheets. The worksheets provide a link between the abstract mathematical concepts presented throughout the course and the concrete, culturally relevant experiences offered by the community. As an example, the *Nasi Hadap-hadapan* tradition is used in the worksheet to introduce the concept of ratios. In using this tradition, students can begin to see mathematical patterns in a familiar social context.

To empirically validate the model's effectiveness, two assessments, the mathematical communication test and the curiosity scale, were developed to assess students' ability to verbalize mathematical thinking and their desire to investigate complex problems, respectively. These assessments aligned with the program's learning objectives.

3.3 Validation Results

In order to protect the integrity of the validation process, the team of experts who reviewed MCPOGIL model was required to adhere to strict professional requirements. Each of the five validators had master degree in mathematic education or higher, and at least 5 years of professional experience in their respective fields. The panel consisted of a curriculum expert to assess whether the model was aligned with the *Kurikulum Merdeka*, a teaching media expert to assess the design and usability of the digital and print materials, and content experts to check the mathematical accuracy of the "ratio and proportion" unit. Thus, they collectively assessed the model from three perspectives: pedagogy, technology, and content. Table 6 presents the quantitative results of the expert review, including the validity scores for all components of the instruction system.

Table 6. Expert Validation Results for Malay Culture-Based POGIL Materials

No	Material Evaluated	Average Score (Va)	Validity Category
1	MCPOGIL Model Book	4.61	Very Valid
2	Teaching Modules & Teacher's Manual	4.28	Very Valid
3	Student Textbook	4.22	Very Valid
4	Student Worksheets	4.20	Valid
5	Communication Test & Curiosity Scale	4.58	Very Valid

Note: The validity category is determined based on the average score (Va) using the following criteria: 4.21 ≤ Va ≤ 5.00 (Very Valid), 3.41 ≤ Va ≤ 4.20 (Valid), 2.61 ≤ Va ≤ 3.40 (Quite Valid), 1.81 ≤ Va ≤ 2.60 (Less Valid), and 1.00 ≤ Va ≤ 1.80 (Invalid).

The overall validity of most components of the MCPOGIL model, as shown in table 6, was found to fall within the "very valid" range. This provides theoretical support for the use of Malay-Asahan cultural elements within the POGIL syntax. The experts also offered qualitative suggestions that improved the prototype. In particular, the curriculum expert suggested allocating specific time to complete both the "Navigate" and "Structuring" phases to prevent students from being overwhelmed cognitively. Additionally, the media expert suggested increasing the visual contrast between the student worksheets and the cultural illustrations to better engage students. Once the above-mentioned improvements have been made to prototype I and transitioned to prototype II, the materials will be ready for practical field testing.

3.4 Field Trial Results (Trials 1 and 2): Practicality

Table 7. Results of Student Response Questionnaire in Trials 1 and 2

No	Aspect of Response	Trial 1 (Using Prototype I)		Trial 2 (Using Prototype II)	
		Positive Response (%) (N = 34)	Category	Positive Response (%) (N = 34)	Category
1	Students' positive feelings toward learning components	91.76%	Very Positive	91.17%	Very Positive
2	Novelty of the learning components and atmosphere	90.59%	Very Positive	93.53%	Very Positive
3	Interest in following future MCPOGIL lessons	100.00%	Very Positive	100.00%	Very Positive
4	Clarity of language used in textbook and worksheets	88.24%	Positive	88.24%	Positive
5	Visual appeal (illustrations and layout) of materials	89.70%	Positive	88.24%	Positive
Average	Total Student Response Score	92.06%	Very Positive	92.24%	Very Positive

Students’ perceptions of the practicability of MCPOGIL model in trial 1 were evaluated through a student response questionnaire administered to students after each session. The questionnaire included five main areas: 1) students’ attitudes toward the various aspects of the program; 2) the novelty of this program to them; 3) their willingness to use this program again in the future; 4) clarity of the language used in the materials; and 5) the visual appeal of the materials. Results from the students’ answers to these questions are presented in Table 7.

The mean student score for the use of the MCPOGIL model was 92.06%, which would be classified as "Very Positive". The most significant aspect is that all students indicated they want to continue the mathematics course using this model. This shows the inclusion of the Malay-Asahan culture to increase students' interest in mathematics. There are, however, aspects of each item that need improvement. Although the responses were very positive, the clarity of the language used on the worksheets and the visual presentation of the worksheets had the lowest relative scores (88.24% and 85.29%, respectively). The students noted that some illustrations of cultural images on the worksheets were slightly overcrowded and that some instructions in the "Structuring" phase were somewhat difficult to follow. These issues were the basis for the changes that will be made prior to trial 2, in particular, simplifying the worksheet layout and improving the instructions so they are easier for students to understand.

The feasibility evaluation in trial 2 tested a second group of students to validate whether the same response was received with the same model as used by the first group. The responses to the student response questionnaire for this part of the study are shown in Table 7. The data showed that the average score across all students' responses increased slightly to 92.24%, which again falls into the "Very Positive" category. What was most notable was a significant increase in the “Novelty” section (from 90.59% in trial 1 to 93.53% in trial 2), indicating that students found the revised way of integrating their Malay-Asahan culture more unique and interesting than before. The "Future lesson interest" remained at 100%, reinforcing that the model has been successful in providing an enjoyable way to learn mathematics.

The comparison of both trials demonstrates that the clarity of the language and visual attractiveness were constant (at 88.24%). These findings suggest that MCPOGIL syntax is easy for students to follow, but it will also create a very supportive social structure for learning mathematics. Since both trials exceeded the practicality threshold of 80% positive responses, MCPOGIL model and supporting materials were deemed practical for wide-scale use.

3.5 Field Trial Results (Trials 1 and 2): Effectiveness

Table 8. Normality Testing Results

Datasets	Shapiro-Wilk			Decision
	Statistic	df	Sig.	
T1_Comm_Pre	0.937	34	0.051	Normal
T1_Comm_Post	0.820	34	< 0.001	Not Normal
T1_Curi_Pre	0.940	34	0.063	Normal
T1_Curi_Post	0.854	34	< 0.001	Not Normal
T2_Comm_Pre	0.934	34	0.040	Not Normal
T2_Comm_Post	0.962	34	0.281	Normal
T2_Curi_Pre	0.971	34	0.493	Normal
T2_Curi_Post	0.942	34	0.070	Normal

Before performing an inferential statistical analysis to determine whether MCPOGIL model was effective, a Shapiro-Wilk normality test was conducted for each variable of interest. This test was chosen because of the relatively small sample size (N=34) for this type of classroom-level research; it is much more sensitive than other tests to deviations from a normal distribution. In addition to describing the results of the normality test in Table 8, the p-values associated with each test are provided. As demonstrated in Table 8, all three datasets had very low p-values for their respective tests (i.e., $p < 0.001$). That is, for each dataset, the null hypothesis of normality can be rejected at the 0.05 level. In addition to these results, the pretest data for communication in trial 2 also failed the normality test ($p = 0.04$). Together, these results suggest that the datasets were highly skewed and thus likely subject to a ceiling effect. That is, many of the students in the trials achieved high levels of performance after being administered the intervention. Because several key variables violated the normality assumption, the study did not conduct a homogeneity-of-variance test. Homogeneity of variance is a specific requirement for performing t-tests (parametric tests). Therefore, the study used nonparametric tests, which do not require the data to be normally distributed or for the variances across groups to be equal.

The Wilcoxon Signed-Rank Test results as seen in table 9 demonstrate that for all variables in both trials 1 and 2, a p-value of < 0.001 was obtained. This demonstrates increased student curiosity and a statistically significant improvement in their ability to communicate mathematically when using MCPOGIL model. The absolute Z-value values (range 4.463-5.090) are far greater than the critical Z-value of 1.96. This supports the notion that integrating the Malay-Asahan cultural context into the POGIL syntax has bridged the gap between students' prior knowledge and mathematical concepts, providing a profound positive impact on their learning.

Table 9. Wilcoxon Test Among Variables Within Trials

Statistics	T1_Comm_Post - T1_Comm_Pre	T1_Curi_Post - T1_Curi_Pre	T2_Comm_Post - T2_Comm_Pre	T2_Curi_Post - T2_Curi_Pre
Z	-5.090	-4.463	-5.090	-5.088
Asymp. Sig. (2-tailed)	< 0.001	< 0.001	< 0.001	< 0.001

The statistical analysis using the Mann-Whitney U Test as presented in Table 10 shows a large, statistically significant difference in student performance after trial 1 compared to trial 2 in both areas tested, namely mathematical communication skills and student curiosity ($p < 0.001$). The Z values of -5.333 and -4.474 further support the conclusion that the students' post-test scores in the second trial were significantly higher than those in the first trial. The increased student performance in the second trial can be directly related to the changes made to the MCPOGIL model following the initial field testing. In particular, refining the Malay-Asahan cultural context and defining POGIL syntax in the instructional material led to a more effective learning experience in the second trial than in the first. Thus, the research objectives were met by creating an optimized learning environment for students.

Table 10. Effect Size of the Wilcoxon Signed-Rank Test

Variable	Z	N	Effect Size (r)	Interpretation
Mathematical Communication (Trial 1)	-5.090	34	0.873	Large
Curiosity (Trial 1)	-4.463	34	0.765	Large
Mathematical Communication (Trial 2)	-5.090	34	0.873	Large
Curiosity (Trial 2)	-5.088	34	0.873	Large

To complement the Wilcoxon Signed-Rank Test, effect sizes were calculated using the formula $r=\frac{|Z|}{\sqrt{N}}$, where N=34.

As presented in Table 10, all effect sizes were classified as large according to Cohen's (1988) criteria. Mathematical communication produced effect sizes of $r = 0.873$ in both Trial 1 and Trial 2, indicating a substantial practical impact of the MCPOGIL model on students' mathematical communication skills. Likewise, students' curiosity demonstrated a large effect in both implementation trials, with effect sizes of $r = 0.765$ in Trial 1 and $r = 0.873$ in Trial 2. These findings indicate that the observed improvements were not only statistically significant ($p < 0.001$) but also educationally meaningful, confirming the strong practical effectiveness of the developed MCPOGIL model.

Table 11. Mann-Whitney U Test Results Comparing Trials 1 and 2 Effectiveness

Statistics	Comm_Post	Curi_Post
Mann-Whitney U	148.000	213.500
Wilcoxon W	743.000	808.500
Z	-5.333	-4.474
Asymp. Sig. (2-tailed)	< 0.001	< 0.001

Spearman's Rho correlation analysis in Table 11 revealed there was no statistically significant association between students' mathematical communication skills and their curiosity levels ($r = -0.091$, $p = 0.610$). Even though the MCPOGIL model showed increases in both variables separately, the increase in curiosity did not indicate how much higher students' communication skills would be. Therefore, this indicates that within a Malay-Asahan culture-based learning framework, these two domains are developing independently. For example, a student can be extremely curious regarding the cultural aspects of the learning experience and yet lack the linguistic/mathematical skills to express those curiosities, or vice versa, a student can have the skills to effectively express themselves through mathematics due to the development of cognitive abilities but remain relatively low in their curiosity levels.

Table 12. Spearman's Rho Correlation Analysis Between Mathematical Communication and Curiosity (Trial 2)

Variables	Statistics	T2_Comm_Post	T2_Curi_Post
T2_Comm_Post	Correlation Coefficient	1.000	-0.091
	Sig. (2-tailed)	.	0.610
	N	34	34
T2_Curi_Post	Correlation Coefficient	-0.091	1.000
	Sig. (2-tailed)	0.610	.
	N	34	34

Table 13. Descriptive Statistics of Students' Mathematical Communication Scores and N-Gain in Trials 1 and 2

Trial	Test	N	Mean	SD	Minimum	Maximum	Mean N-Gain	Hake Category
Trial 1 (Class VII-A)	Pretest	34	0.409	0.123	0.222	0.694	–	–
	Posttest	34	0.706	0.075	0.472	0.806	0.477	Moderate
Trial 2 (Class VII-B)	Pretest	34	0.620	0.061	0.528	0.778	–	–
	Posttest	34	0.801	0.057	0.667	0.917	0.463	Moderate

Table 13 presents the descriptive statistics of students' mathematical communication scores in both field trials. In Trial 1, the mean pretest score increased from 0.409 (SD = 0.123) to 0.706 (SD = 0.075) after implementing the MCPOGIL model. The average normalized gain was 0.477, which falls into the moderate category according to Hake (1999), indicating a moderate improvement in students' mathematical communication skills.

Similarly, in Trial 2, the mean score increased from 0.620 (SD = 0.061) on the pretest to 0.801 (SD = 0.057) on the posttest. The average normalized gain reached 0.463, which is also classified as moderate according to Hake's criteria. These findings indicate that the revised MCPOGIL model consistently improved students' mathematical communication skills across both implementation trials.

Table 14. Descriptive Statistics of Students' Curiosity Scores and N-Gain in Trials 1 and 2

Trial	Test	N	Mean	SD	Minimum	Maximum	Mean N-Gain	Hake Category
Trial 1 (Class VII-A)	Pretest	34	0.576	0.039	0.463	0.663	–	–
	Posttest	34	0.707	0.093	0.544	0.825	0.301	Moderate
Trial 2 (Class VII-B)	Pretest	34	0.618	0.033	0.550	0.694	–	–
	Posttest	34	0.804	0.055	0.688	0.888	0.484	Moderate

Table 14 presents the descriptive statistics of students' curiosity scores before and after the implementation of the MCPOGIL model. In Trial 1, the mean curiosity score increased from 0.576 (SD = 0.039) on the pretest to 0.707 (SD = 0.093) on the posttest. The average normalized gain (N-Gain) was 0.301, which falls into the moderate category according to Hake (1999). Likewise, in Trial 2, the mean curiosity score improved from 0.618 (SD = 0.033) to 0.804 (SD = 0.055). The average N-Gain reached 0.484, which is also classified as moderate. These findings indicate that the revised MCPOGIL model produced a consistent and meaningful improvement in students' curiosity across both implementation trials.

Table 15. Percentage of Students Achieving the High Curiosity Threshold

Trial	Number of Students (N)	Students Achieving High Curiosity (n)	Percentage (%)	Category
Trial 1 (Class VII-A)	34	22	64.71	Moderate
Trial 2 (Class VII-B)	34	32	94.12	High

Table 15 shows the percentage of students who achieved the predetermined high-curiosity threshold after the implementation of the MCPOGIL model. In Trial 1, 22 out of 34 students (64.71%) reached the high-curiosity criterion, indicating that the model had not yet met the effectiveness criterion requiring at least 80% of students to achieve the target. Following revisions to the instructional materials, Trial 2 showed a substantial improvement, with 32 out of 34 students (94.12%) attaining the high-curiosity threshold. This result exceeded the predetermined effectiveness criterion of 80%, indicating that the revised MCPOGIL model was effective in enhancing students' curiosity.

Based on observation data on teachers' learning management skills in Trial I and Trial II, the following is a summary of the average scores for each phase of MCPOGIL syntax, which can be presented in a table as requested by the reviewer. Data are taken from the "Mean Score" values for each phase.

Table 16. Classroom Observation Results on the Implementation of MCPOGIL Learning Syntax

MCPOGIL Phase	Trial 1	Trial 2	Improvement
Initiate (Orientation)	3.08	3.96	+0.88
Navigate (Exploration)	3.17	3.33	+0.16
Structuring (Concept Construction)	2.59	3.53	+0.94
Present (Presentation)	3.00	4.00	+1.00
Integrate (Application)	2.75	3.50	+0.75
Reflect and Empower (Reflection)	2.85	3.63	+0.78
Overall Mean	2.90	3.64	+0.74

Table 16 summarizes the classroom observation results regarding the teacher's implementation of the MCPOGIL learning syntax during the two field trials. The overall implementation score improved from 2.90 in Trial 1 to 3.64 in Trial 2, indicating that the revisions made after the first trial substantially improved the practicality of the instructional model. The greatest improvement was observed in the Present phase, which increased from 3.00 to 4.00, followed by the Structuring phase, which increased from 2.59 to 3.53. Improvements were also observed in the Initiate, Integrate, and Reflect and Empower phases. These findings indicate that the revised MCPOGIL model was implemented more consistently and effectively during the second field trial, supporting its practicality for classroom use.

Based on data from Teacher Responses to Learning Components and Activities in Trials I and II, the following summary table conforms to the format of an international journal article. Percentages are calculated using the average of the highest categories ("Very Helpful" and "Very Good") as an indicator of the practicality of the learning tools.

Table 17. Teachers' Responses to the Practicality of the MCPOGIL Model

Aspect	Percentage (%)	Category
Trial 1		
Learning Components and Activities	80.00	Very Practical
Quality of Learning Components	77.50	Practical
Overall Teacher Response (Trial 1)	78.75	Practical
Trial 2		
Learning Components and Activities	92.50	Very Practical
Quality of Learning Components	95.00	Very Practical
Overall Teacher Response (Trial 2)	93.75	Very Practical

Table 17 presents the teachers' responses to the practicality of the MCPOGIL model during the two field trials. In Trial 1, the average teacher response reached 78.75%, indicating that the developed learning materials were practical for classroom implementation. After revisions based on the first trial, the average teacher response increased to 93.75% in Trial 2, which falls into the very practical category. The improvements demonstrate that the revisions successfully enhanced the quality, usability, and implementation of the MCPOGIL learning components, thereby strengthening the practicality of the developed instructional model.

3.6 Final Product Description

The ultimate product of this research is a coordinated instructional system of four primary elements. Each element was tested and validated by subject matter experts through multiple cycles of field testing.

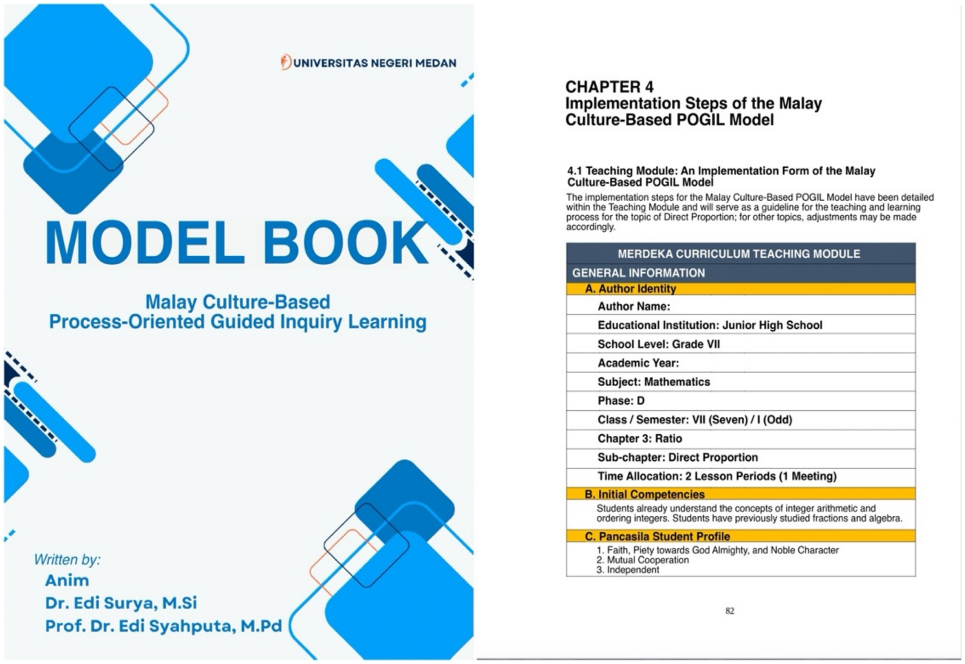

Figure 2. The MCPOGIL Model Book: Front Cover and Instructional Guidelines for Module Development

The core element of this instructional system is MCPOGIL model book (see Figure 2). The model book represents both the theoretical and operational foundation upon which all other instructional components of the system will be built. The model book provides the educator with a complete and thorough guide in Chapter 4 regarding the practical application of the model and the development of culturally based teaching modules aligned with the *Kurikulum Merdeka*. To assist the educators in delivering the model, a teaching module and a teacher's manual were developed and will serve as an instructional roadmap.

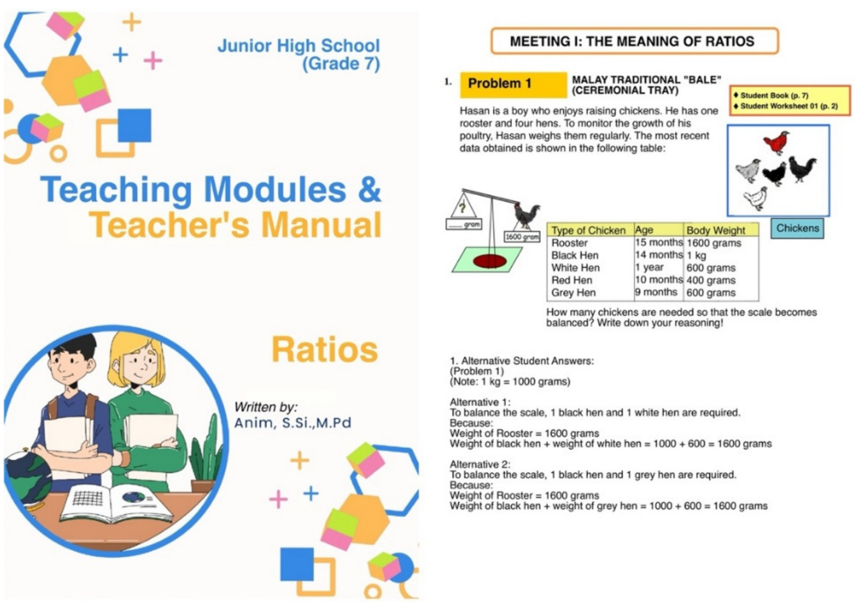

Figure 3. Teaching Module and Teacher's Manual: Front Cover and Meeting I, Highlighting the Malay-Asahan *"Bale"* (Ceremonial Tray) Context

The design of the teacher's manual is presented in Figure 3 and demonstrates how it uses the artifacts of the Malay-Asahan culture, i.e., the *Bale* (ceremonial tray), as a concrete stimulus during the initial meeting to introduce mathematical inquiry through local customs. In addition to the teacher's resources, the instructional resources designed to allow students to construct knowledge in a student-centered manner and to link abstract logic to sociocultural reality include the student textbook and the student worksheets.

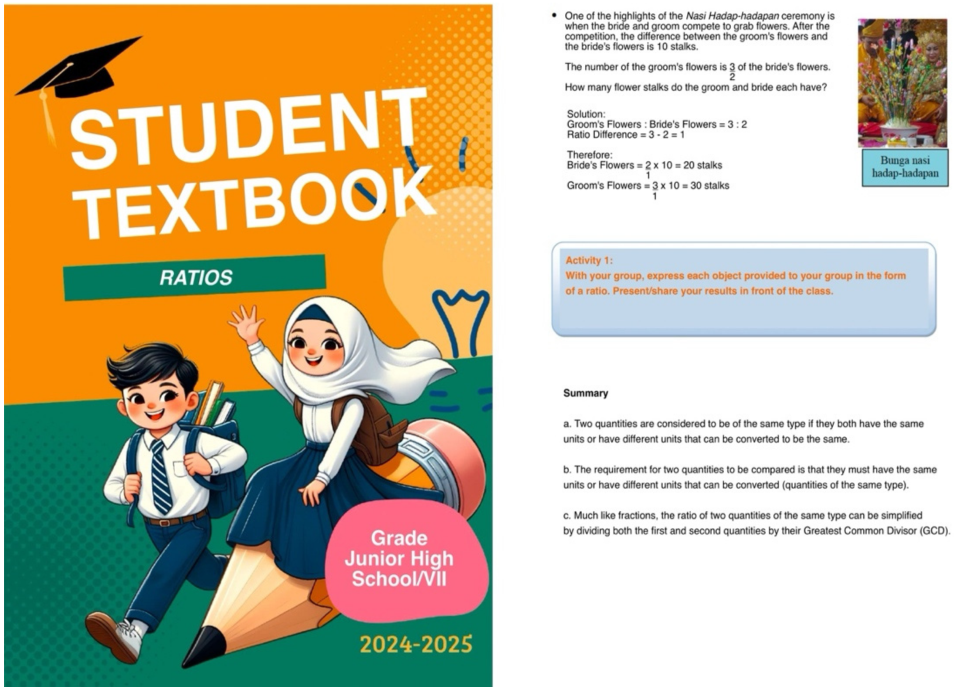

Figure 4. Student Mathematics Textbook: Front Cover and Ratio Problem Sets using the "*Bunga Nasi Hadap-hadapan*" Context

The student textbook (see Figure 4) provides the conceptual foundation for the ratio and proportion unit, using cultural symbols familiar to students (e.g., the *Nasi Hadap-hadapan Flowers*) to illustrate mathematical problems in meaningful contexts. In doing so, this method enables the students to use visual aids of the social patterns of their own community to visualize mathematical ratios.

The student worksheets (presented in Figure 5) provide the primary mechanism for students to engage in the active process of constructing knowledge. The finalized worksheets have been streamlined and include a variety of problem types (e.g., problems 7 and 8). These problems require students to use ratio concepts to solve problems with real-life applications in their local community.

Based on the predetermined validity criteria, the Student Worksheets obtained an average validity score of Va = 4.20, which falls within the interval of $3.41 \leq Va \leq 4.20$ and is therefore categorized as Valid. The Very Valid category begins at $Va \geq 4.21$. Thus, the categorization applied in this study follows the predefined interval boundaries consistently.

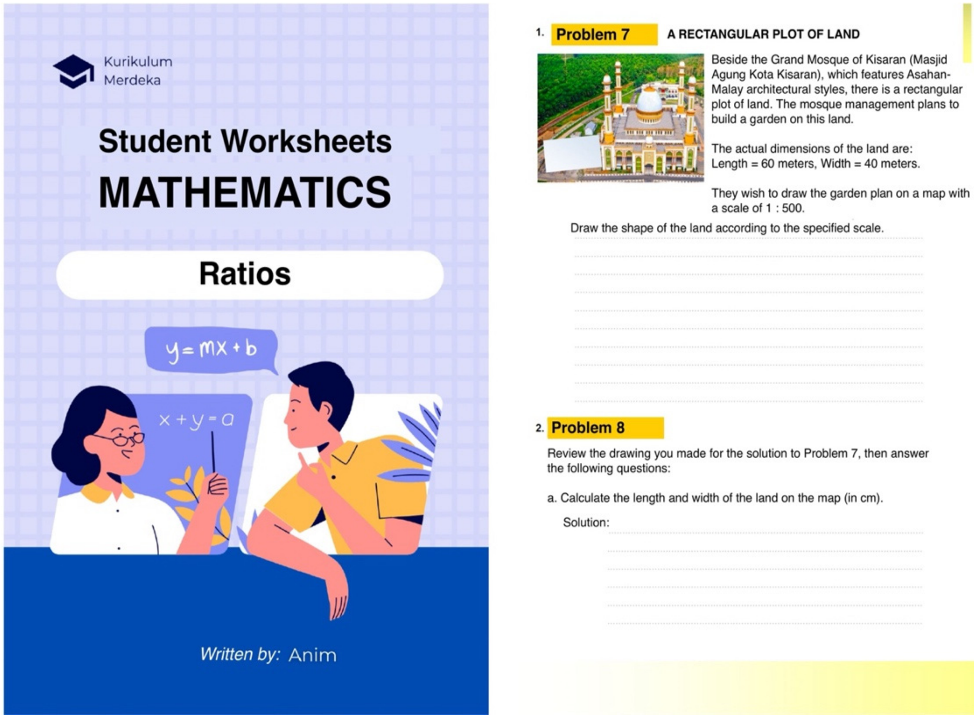

Figure 5. Student Worksheets: Front Cover and Finalized Problem Sets 7 and 8 on Ratio and Proportion

4. Discussion

The motivation behind developing the MCPOGIL model is to move away from traditional teacher-centered instructional methods toward a new generation of student-centered methods that align with the *Kurikulum Merdeka*. The results of this research show that this model is not only valid and practical but also very successful at developing both the cognitive (communication) and affective (curiosity) domains. The statistically significant increase in students' ability to communicate mathematically ($p < 0.001$) demonstrates that the POGIL-guided inquiry method's structure promotes the social construction of knowledge. Students using the Malay Culture-Based POGIL model go through an exploratory phase and then a conceptual formation phase; they are forced to express their thoughts verbally when articulating an abstract idea. This aligns with Simonson (2019), who found that the collaborative aspect of POGIL creates a safe space for students to engage in mathematical discourse. Additionally, students' use of the Malay-Asahan cultural context (for example, local trading and *Nasi Hadap-hadapan*) to anchor their mathematical expressions reduces cognitive load, as they can discuss social phenomena they are familiar with before formally expressing them as mathematical ratios. This supports Abd Jalil & Abdullah (2023) argument for culturally responsive pedagogy, in which local wisdom is used to build bridges to the abstract logic of mathematics.

The effectiveness of POGIL in enhancing mathematical communication can be explained through its emphasis on collaborative inquiry and the social construction of knowledge (Catriz, 2025; Farda et al., 2017; Fateh et al., 2024; Kartono & Shora, 2020; Kussmaul & Pirmann, 2022; Madiclum & Prudente, 2025; Mamombe et al., 2022; Nurtamam et al., 2024; Rodriguez et al., 2020; Yadav et al., 2021). Rather than receiving mathematical procedures through direct instruction, students work collaboratively in small groups to explore problems, identify patterns, formulate concepts, and justify their conclusions. Throughout this inquiry process, learners are required to verbalize their thinking, explain solution strategies, question alternative viewpoints, and negotiate meaning with peers before reaching a shared understanding. These learning activities promote mathematical communication by encouraging students to express mathematical ideas using appropriate language, representations, symbols, and logical arguments. From a sociocultural perspective, these interactions provide opportunities for students to construct knowledge through dialogue, where communication functions not merely as a means of reporting solutions but also as a cognitive tool for developing conceptual understanding. Furthermore, the structured phases of POGIL—including exploration, concept formation, organization, and application—guide students progressively from concrete observations to abstract mathematical reasoning while continuously requiring explanation and reflection. Consequently, mathematical communication develops as students repeatedly articulate, refine, and defend their reasoning during collaborative inquiry rather than passively receiving information from the teacher.

The very high levels of practicality (92.24%), along with the large Z-value for the curiosity scale (Z = -5.088 in trial 2), indicate that the culture-specific component was the most influential factor in student engagement. This fact is also supported by previous studies that cultural component affects the teaching-learning process including students' engagement (Chuanzhu, 2025; Jose & Tagadiad, 2025; Lam et al., 2016; Rahmiwati et al., 2026; Shcheglova, 2018). The use of a "novelty" aspect in the model, drawing on their own cultural heritage to understand math, led students to feel a sense of "ownership".

From the perspective of ethnomathematics, the incorporation of local cultural knowledge also functioned as a source of cognitive novelty that stimulated students' epistemic curiosity. Rather than merely receiving mathematical procedures from the teacher, students were encouraged to investigate how mathematical principles are embedded in traditional Malay cultural practices, prompting them to ask exploratory questions such as why particular mathematical patterns emerge and how these concepts are applied in real-life cultural contexts. Such inquiry aligns with the fundamental principles of POGIL, in which learning is driven by exploration, collaborative reasoning, and the construction of knowledge through guided investigation. Previous studies have likewise reported that ethnomathematical contexts encourage students to engage more actively in mathematical inquiry, promote deeper conceptual understanding, and stimulate curiosity by linking mathematics with familiar cultural experiences (Irawan et al., 2022; Noto et al., 2018; Novelza et al., 2023).

The most notable finding was that there was no relationship between the students' communication skills and their curiosity ($r = -0.091$, $p = 0.610$). Although both variables increased significantly during this period of instruction, they did not increase together. Therefore, we believe that MCPOGIL model is stimulating two independent areas of a student's learning. For example, a student may have excellent mathematical communication skills due to their strong logical-linguistic intelligence, yet not be curious about the problem's cultural origins. Alternatively, a student may be extremely curious about the *Nasi Hadap-hadapan* tradition; however, he/she may be struggling with the formal mathematical language used to express ratios.

The results of the Mann-Whitney U test ($p < 0.01$) show that trial 2 performed better than trial 1, as evidence that the iterative design process of the Plomp development models works. The two "pivot points" suggested by experts ("timing" and "clarity") were critical to modifying the "Navigate" and "Structuring" aspects of the model to avoid "cognitive overload" from discovery-based instruction. By doing this, the model was "refined" to be classroom-tested as well as theoretically grounded, which will help implement the model throughout the Asahan region.

The significantly better performance observed during the second field trial reflects the effectiveness of the iterative refinement process that characterizes educational design research. Following the first implementation, several aspects of the MCPOGIL prototype were revised based on expert recommendations, classroom observations, teacher feedback, and student responses. The most substantial revisions included simplifying the instructional language, improving the visual design and contrast of the learning materials, clarifying activity instructions, and strengthening the integration of Malay-Asahan cultural contexts within the inquiry activities. These modifications addressed practical barriers that had limited students' participation during the first trial and created a more accessible learning environment for collaborative inquiry.

From a theoretical perspective, simplifying the instructional language and improving the visual organization of the learning materials likely reduced students' extraneous cognitive load, allowing greater cognitive resources to be devoted to mathematical reasoning and problem solving. At the same time, the enhanced cultural representations increased the authenticity and personal relevance of learning activities, enabling students to connect abstract mathematical concepts with familiar cultural experiences. These contextual improvements are consistent with ethnomathematics, which emphasizes that culturally meaningful contexts promote deeper engagement and conceptual understanding. Furthermore, clearer inquiry prompts encouraged richer classroom dialogue and collaborative reasoning, aligning with the principles of Process-Oriented Guided Inquiry Learning (POGIL), where knowledge is constructed through discussion, reflection, and shared problem solving. Consequently, the revisions implemented after the first trial not only improved the usability of the instructional materials but also strengthened the pedagogical mechanisms through which the MCPOGIL model enhanced students' mathematical communication skills and curiosity.

In addition to enhancing students' mathematical communication, this study considers student curiosity as a key affective outcome that supports meaningful mathematical learning. Curiosity refers to an intrinsic desire to acquire new knowledge, explore unfamiliar situations, and resolve uncertainty through active inquiry (Modirshanechi et al., 2023; Renninger & Hidi, 2019). In mathematics education, curiosity encourages students to ask questions, investigate multiple solution strategies, and persist in solving challenging problems rather than relying solely on teacher explanations (Edwards & Robichaux-Davis, 2025; Knuth, 2002; Rahayu et al., 2019; Ruiz-Alfonso & León, 2019; Von Renesse & Ecke, 2017). Previous studies have shown that students with higher levels of curiosity demonstrate greater engagement, deeper conceptual understanding, and stronger problem-solving abilities because they actively construct knowledge instead of passively receiving information. These characteristics closely align with the principles of POGIL which encourages learners to explore, formulate concepts, and collaboratively construct understanding through guided inquiry. Furthermore, integrating culturally meaningful contexts through ethnomathematics may further stimulate students' curiosity by connecting abstract mathematical concepts with familiar cultural practices and everyday experiences. When mathematical problems are embedded within authentic local traditions, students are encouraged to investigate not only mathematical relationships but also the cultural meanings underlying these contexts. Consequently, combining guided inquiry with Malay-Asahan cultural contexts is expected to foster both cognitive development, reflected in mathematical communication, and affective engagement, reflected in students' curiosity.

Despite demonstrating that MCPOGIL model is valid, practical, and effective in improving students' mathematical communication skills and curiosity, several limitations should be acknowledged. First, the study was conducted in a single junior high school, SMPN 2 Kisaran, North Sumatra, which may limit the generalizability of the findings to schools with different cultural, socioeconomic, or educational contexts. Second, the field trials involved relatively small samples of 34 students in each implementation stage. Although this sample size is appropriate for educational design research and iterative model refinement, larger and more diverse samples are needed to strengthen the external validity of the findings. Third, the intervention was implemented over a relatively short period, allowing evaluation of immediate learning outcomes but not the long-term sustainability of students' mathematical communication skills and curiosity. Longitudinal studies are therefore needed to examine whether these improvements are maintained over time. Finally, this study adopted a development research approach and did not include a control group receiving conventional instruction. Consequently, while significant improvements were observed following the implementation of MCPOGIL, causal comparisons with alternative instructional approaches cannot be established. Future studies are encouraged to evaluate the model using quasi-experimental or randomized controlled designs involving multiple schools from different regions of Indonesia. Such investigations would provide stronger evidence regarding the effectiveness, scalability, and broader applicability of the MCPOGIL model across diverse educational settings.

The findings of this study have several important implications for mathematics teaching, school practice, and curriculum implementation. The demonstrated validity, practicality, and effectiveness of MCPOGIL model suggest that it can serve as a practical instructional framework for promoting both cognitive and affective learning outcomes in junior high school mathematics. Rather than relying predominantly on teacher-centered instruction, mathematics teachers can adopt the MCPOGIL model to facilitate collaborative inquiry, encourage students to articulate mathematical reasoning, and connect abstract concepts with meaningful cultural experiences.

Successful implementation of MCPOGIL, however, requires adequate teacher preparation. Teachers should be equipped not only with knowledge of inquiry-based instructional strategies but also with the pedagogical skills needed to facilitate collaborative learning, guide classroom discussions, and encourage students to justify mathematical reasoning rather than simply provide correct answers. Professional development programs should therefore include training on designing inquiry activities, integrating local cultural contexts into mathematics lessons, and assessing mathematical communication alongside affective outcomes such as curiosity. Developing teachers' competence in culturally responsive pedagogy is equally important, as effective implementation depends on their ability to identify authentic cultural practices that meaningfully represent mathematical concepts while remaining aligned with curriculum objectives.

5. Conclusion and Suggestion

This study developed and evaluated the Malay Culture-Based Process-Oriented Guided Inquiry Learning (MCPOGIL) model to enhance junior high school students' mathematical communication skills and curiosity. The findings demonstrate that the developed model satisfies the criteria of validity, practicality, and effectiveness. Expert validation indicated that the model and its supporting learning materials achieved validity scores within the valid to highly valid category. The practicality evaluation yielded a mean score of 92.24%, indicating that the model was highly practical for classroom implementation. Furthermore, students' mathematical communication skills and curiosity improved significantly following the implementation of the MCPOGIL model, as evidenced by the

Wilcoxon Signed-Rank Test, while the Mann–Whitney U Test showed significantly better outcomes in the second field trial than in the first. Collectively, these findings suggest that integrating guided inquiry with culturally meaningful mathematical contexts can support both cognitive and affective aspects of mathematics learning.

Nevertheless, the findings should be interpreted within the scope of the present study. The model was implemented in a single junior high school involving a relatively small sample of students, focused on one mathematical topic, and employed a development research design without a control group. Consequently, while the results provide encouraging evidence regarding the validity, practicality, and classroom effectiveness of the MCPOGIL model in the studied context, they should not be interpreted as establishing broad causal effectiveness or generalized directly to other educational settings.

Future research should prioritize three directions. First, the model should be evaluated through multi-site quasi-experimental or randomized studies involving larger and more diverse student populations to strengthen evidence of its effectiveness and external validity. Second, future investigations should examine the applicability of MCPOGIL across different mathematical topics and grade levels to determine its pedagogical consistency throughout secondary mathematics education. Finally, further research should explore the adaptation of the model to different cultural communities by preserving its inquiry-based instructional framework while integrating locally relevant ethnomathematical contexts, thereby examining its transferability across diverse educational and cultural settings.

References

Abd Jalil, A. H., & Abdullah, A. H. (2023). Indigenous Pedagogy Approach in Teaching Mathematics among Orang Asli Primary School Students. *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, *8*(9), e002494. https://doi.org/10.47405/mjssh.v8i9.2494

Ahmedi, V., Kurshumlija, A., & Ismajli, H. (2023). Teachers `Attitudes towards Constructivist Approach to Improving learning outcomes: The Case of Kosovo. *International Journal of Instruction*, *16*(1), 441-454. https://doi.org/10.29333/iji.2023.16124a

Andriani, S., Nurlaelah, E., & Yulianti, K. (2019). The effect of process oriented guided inquiry learning (POGIL) model toward students' logical thinking ability in mathematics. *Journal of Physics: Conference Series*, *1157*, 042108. https://doi.org/10.1088/1742-6596/1157/4/042108

Ardianti, Y., & Amalia, N. (2022). Kurikulum Merdeka: Pemaknaan Merdeka dalam Perencanaan Pembelajaran di Sekolah Dasar. *Jurnal Penelitian Dan Pengembangan Pendidikan*, *6*(3), 399-407. https://doi.org/10.23887/jppp.v6i3.55749

Barthlow, M. J., & Watson, S. B. (2014). The Effectiveness of Process-Oriented Guided Inquiry Learning to Reduce Alternative Conceptions in Secondary Chemistry. *School Science and Mathematics*, *114*(5), 246-255. https://doi.org/10.1111/ssm.12076

Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. *Science Education*, *94*(5), 765-793. https://doi.org/10.1002/sce.20402

Brown, J. C. (2017). A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *Journal of Research in Science Teaching*, *54*(9), 1143-1173. https://doi.org/10.1002/tea.21401

Cai, J., Jakabcsin, M. S., & Lane, S. (1996). Assessing Students' Mathematical Communication. *School Science and Mathematics*, *96*(5), 238-246. https://doi.org/10.1111/j.1949-8594.1996.tb10235.x

Catriz, L. J. (2025). Levels of attainment on Higher-Order Thinking Skills in Math through Process-Oriented Guided Inquiry Learning (POGIL) using scaffolding and digital tools. *Pantao (International Journal of the Humanities and Social Sciences)*, *4*(3). https://doi.org/10.69651/PIJHSS0403469

Chuanzhu, H. (2025). The Influence of Culturally Responsive Teaching on Student Engagement in Shandong Secondary School Diverse Classrooms. *International Journal of Academic Research in Progressive Education and Development*, *14*(2), Pages 1722-1733. https://doi.org/10.6007/IJARPED/v14-i2/25617

Edwards, C., & Robichaux-Davis, R. (2025). Stimulating Curiosity in Mathematics. *Mathematics Teacher: Learning and Teaching PK-12*, *118*(9), 650-652. https://doi.org/10.5951/MTLT.2025.0266

Fadillah, C. N., & Yusuf, H. (2022). Analisis Kurikulum Merdeka Dalam Satuan Pendidikan Anak Usia Dini. *Jurnal*

Bunga Rampai Usia Emas, *8*(2), 120-137. https://doi.org/10.24114/jbrue.v8i2.41596

Farda, H., Zaenuri, Z., & Sugiarto, S. (2017). Effectiveness of POGIL Learning Model with Ethnomathematics Nuance Assisted by Student Worksheet toward Student Mathematical Communication Skill. *Unnes Journal of Mathematics Education*, *6*(2), 223-230. https://doi.org/10.15294/ujme.v6i2.15812

Fateh, S., Ayangbola, O. T., Reid, J. W., Zakher, S. W., Kirbulut Gunes, Z. D., Phelps, A. J., Malone, A., & Rushton, G. T. (2024). Small Group Conversations in a POGIL-Based Class: How English Learners Engage in a Joint Knowledge Construction Process to Reach a Shared Understanding. *Journal of Chemical Education*, *101*(3), 741-752. https://doi.org/10.1021/acs.jchemed.2c00624

Fitra, D. (2023). Kurikulum Merdeka dalam Pendidikan Modern. *Jurnal Inovasi Edukasi*, *6*(2), 149-156. https://doi.org/10.35141/jie.v6i2.953

Gay, G. (2002). Preparing for Culturally Responsive Teaching. *Journal of Teacher Education*, *53*(2), 106-116. https://doi.org/10.1177/0022487102053002003

Ghany, W. A., Cahya M, E., & Juandi, D. (2024). Mathematical Communication Skills of Junior High School Students in Solving Straight Line Equation Problems Based on Learning Interest. *KnE Social Sciences*, 219-228. https://doi.org/10.18502/kss.v9i13.15922

Hainun, H., Haeruddin, H., & Basir, A. (2022). Literature Review: Model Process Oriented Guided Inquiry Learning (POGIL) Pada Pembelajaran Matematika. *Primatika: Jurnal Pendidikan Matematika*, *11*(1), 61-70. https://doi.org/10.30872/primatika.v11i1.796

Hein, S. M. (2012). Positive Impacts Using POGIL in Organic Chemistry. *Journal of Chemical Education*, *89*(7), 860-864. https://doi.org/10.1021/ed100217v

Hiebert, J., & Grouws, D. A. (2007). *The Effects of Classroom Mathematics Teaching on Students' Learning* (F. Lester (Ed.), Second Handbook of Research on Mathematics Teaching and Learning). Information Age.

Johnson, C. C. (2011). The road to culturally relevant science: Exploring how teachers navigate change in pedagogy. *Journal of Research in Science Teaching*, *48*(2), 170-198. https://doi.org/10.1002/tea.20405

Jose, G. P., & Tagadiad, C. L. (2025). School Culture Elements and Intellectual Stimulaton as Predictors of Student Engagement in School. *International Journal of Research and Innovation in Social Science*, *IX*(III), 1447-1463. https://doi.org/10.47772/IJRISS.2025.90300113

Joyce, B. R., Weil, M., & Calhoun, E. (2009). *Models of Teaching*. Allyn Bacon.

Kartono, K., & Shora, R. Y. (2020). Effectiveness of Process Oriented Guided Inquiry Learning with Peer Feedback on Achieving Students' Mathematical Reasoning Capabilities. *International Journal of Instruction*, *13*(3), 555-570. https://doi.org/10.29333/iji.2020.13338a

Knuth, E. J. (2002). Fostering Mathematical Curiosity. *The Mathematics Teacher*, *95*(2), 126-130. https://doi.org/10.5951/MT.95.2.0126

Kussmaul, C., & Pirmann, T. (2022). Guided Inquiry Learning with Technology: Community Feedback and Software for Social Constructivism. In B. Csapó & J. Uhomoibhi (Eds.), *Computer Supported Education* (Vol. 1624, pp. 407-428). Springer International Publishing. https://doi.org/10.1007/978-3-031-14756-2_20

Lam, S., Jimerson, S., Shin, H., Cefai, C., Veiga, F. H., Hatzichristou, C., Polychroni, F., Kikas, E., Wong, B. P. H., Stanculescu, E., Basnett, J., Duck, R., Farrell, P., Liu, Y., Negovan, V., Nelson, B., Yang, H., & Zollneritsch, J. (2016). Cultural universality and specificity of student engagement in school: The results of an international study from 12 countries. *British Journal of Educational Psychology*, *86*(1), 137-153. https://doi.org/10.1111/bjep.12079

Litman, J. A., & Jimerson, T. L. (2004). The Measurement of Curiosity As a Feeling of Deprivation. *Journal of Personality Assessment*, *82*(2), 147-157. https://doi.org/10.1207/s15327752jpa8202_3

Madiclum, P. C., & Prudente, M. (2025). A Meta-analysis of the Effectiveness of Process-Oriented Guided Inquiry Learning on Students' Academic Achievement. *International Journal of Humanities and Social Sciences*, *17*(2), 36-51. https://doi.org/10.26803/ijhss.17.2.4

Mamombe, C., Mathabathe, K. C., & Gaigher, E. (2022). From the Familiar to the Abstract: Exploring Grade 11 Learners' Development in Stoichiometry Problem Solving Competency with Exposure to POGIL. *African Journal of Research in Mathematics, Science and Technology Education*, *26*(2), 166-180.

https://doi.org/10.1080/18117295.2022.2115652

Mardiana, M., & Emmiyati, E. (2024). Implementasi Kurikulum Merdeka dalam Pembelajaran: Evaluasi dan Pembaruan. *Jurnal Review Pendidikan Dasar : Jurnal Kajian Pendidikan Dan Hasil Penelitian*, *10*(2), 121-127. https://doi.org/10.26740/jrpd.v10n2.p121-127

Maulyda, M. A., Annizar, A. M., Hidayati, V. R., & Mukhlis, M. (2020). Analysis of students' verbal and written mathematical communication error in solving word problem. *Journal of Physics: Conference Series*, *1538*(1), 012083. https://doi.org/10.1088/1742-6596/1538/1/012083

Modirshanechi, A., Kondrakiewicz, K., Gerstner, W., & Haesler, S. (2023). Curiosity-driven exploration: Foundations in neuroscience and computational modeling. *Trends in Neurosciences*, *46*(12), 1054-1066. https://doi.org/10.1016/j.tins.2023.10.002

Moog, R. S., & Spencer, J. N. (2008). *POGIL: Process Oriented Guided Inquiry Learning*. ACS Symposium Series 994, American Chemical Society, Washington DC.

Muhammad, M., & Purwanto, J. (2020). The effect of Process Oriented Guided Inquiry Learning (POGIL) on mathematical problem solving abilities. *Journal of Physics: Conference Series*, *1469*(1), 012171. https://doi.org/10.1088/1742-6596/1469/1/012171

NCTM. (2000). *Principles and standards for school mathematics*. NCTM (National Council of Teachers of Mathematics).

Nuralif, S. (2025). A Systematic Literatur Review: Implementasi Model POGIL terhadap Kemampuan Matematis Siswa dalam Pembelajaran Matematika. *JIIP - Jurnal Ilmiah Ilmu Pendidikan*, *8*(11), 12654-12662. https://doi.org/10.54371/jiip.v8i11.9667

Nurtamam, M. E., Budayasa, I. K., & Lukito, A. (2024). Process-Oriented Guided Inquiry Learning and Students' Mathematical Reasoning Ability in Indonesia: A Systematic Literature Review and Meta-Analysis. *Tadris: Jurnal Keguruan Dan Ilmu Tarbiyah*, *9*(2), 347-358. https://doi.org/10.24042/tadris.v9i2.21308

OECD. (2023). *PISA 2022 Results (Volume I): The State of Learning and Equity in Education*. OECD Publishing. https://doi.org/10.1787/53f23881-en

Plomp, T., & Nieveen, N. (2013). *Educational Design Research: An Introduction*. SLO.

Putri, E. R., Budiyono, B., & Indriati, D. (2020). POGIL model on mathematical connection ability viewed from self-regulated learning. *International Journal of Evaluation and Research in Education (IJERE)*, *9*(2), 394. https://doi.org/10.11591/ijere.v9i2.20321

Rahayu, C., Putri, R. I. I., Zulkardi, & Hartono, Y. (2019). On curiosity to introduce mathematics in early childhood. *Journal of Physics: Conference Series*, *1166*, 012032. https://doi.org/10.1088/1742-6596/1166/1/012032

Rahmadayanti, D., & Hartoyo, A. (2022). Potret Kurikulum Merdeka, Wujud Merdeka Belajar di Sekolah Dasar. *Jurnal Basicedu*, *6*(4), 7174-7187. https://doi.org/10.31004/basicedu.v6i4.3431

Rahmadhani, E. (2018). Model pembelajaran process oriented guided inquiry learning (POGIL): Peningkatan disposisi matematika dan self-confidence mahasiswa tadris matematika. *Jurnal Riset Pendidikan Matematika*, *5*(2), 159-167. https://doi.org/10.21831/jrpm.v0i0.20962

Rahmiwati, Sulisworo, D., & Hartanto, D. (2026). Influence of Traditional Indonesian Values and Local Culture on Teaching Practices and Student Engagement: A Comparative Study of Rural and Urban Schools. *Jurnal Praktik Baik Pembelajaran Sekolah Dan Pesantren*, *5*(01), 30-46. https://doi.org/10.56741/IISTR.pbpsp.001916

Renninger, K. A., & Hidi, S. E. (2019). *The Cambridge Handbook of Motivation and Learning* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781316823279

Rodriguez, J.-M. G., Hunter, K. H., Scharlott, L. J., & Becker, N. M. (2020). A Review of Research on Process Oriented Guided Inquiry Learning: Implications for Research and Practice. *Journal of Chemical Education*, *97*(10), 3506-3520. https://doi.org/10.1021/acs.jchemed.0c00355

Ruiz-Alfonso, Z., & León, J. (2019). Teaching quality: Relationships between passion, deep strategy to learn, and epistemic curiosity. *School Effectiveness and School Improvement*, *30*(2), 212-230. https://doi.org/10.1080/09243453.2018.1562944

Shcheglova, I. A. (2018). A Cross-Cultural Comparison of the Academic Engagement of Students. *Russian Education & Society*, *60*(8-9), 665-681. https://doi.org/10.1080/10609393.2018.1598163

Simonson, S. R. (2019). *POGIL: An Introduction to Process Oriented Guided Inquiry Learning for Those Who Wish to Empower Learners*. Stylus Publishing LLC.

Taira, B. W., & Maunakea, S. P. (2023). Ma ka hana ka ‘ike: Implementing Culturally Responsive Educational Practices. *Behavior and Social Issues*, *32*(1), 234-248. https://doi.org/10.1007/s42822-023-00127-4

Taylor, L. (1993). Vygotskian Influences in Mathematics Education, with Particular Reference to Attitude Development. *Focus on Learning Problems in Mathematics, 15*, 3-17.

Von Renesse, C., & Ecke, V. (2017). Teaching Inquiry With a Lens Toward Curiosity. *PRIMUS*, *27*(1), 148-164. https://doi.org/10.1080/10511970.2016.1176973

Yadav, A., Mayfield, C., Moudgalya, S. K., Kussmaul, C., & Hu, H. H. (2021). Collaborative Learning, Self-Efficacy, and Student Performance in CS1 POGIL. *Proceedings of the 52nd ACM Technical Symposium on Computer Science Education*, 775-781. https://doi.org/10.1145/3408877.3432373

Yana, N., Masykur, R., & Putra, F. G. (2021). Pengaruh Model Pembelajaran Process Oriented Guided Inquiry Learning (POGIL) Berbantuan Lembar Kerja Peserta Didik Terintegrasi Nilai-Nilai Keislaman terhadap Kemampuan Komunikasi Matematis. *Jurnal Pendidikan Matematika Dan Sains*, *9*(1), 1-6. https://doi.org/10.21831/jpms.v9i1.21444

Yulia, P., Riskayani, M., & Erita, S. (2021). Efektivitas Model Pembelajaran Process Oriented Guided Inquiry Learning (POGIL) terhadap Kemampuan Komunikasi Matematis. *Jurnal Absis : Jurnal Pendidikan Matematika Dan Matematika*, *3*(2), 257-266. https://doi.org/10.30606/absis.v3i2.700

Yuliastini, I. B., Rahayu, S., Fajaroh, F., & Mansour, N. (2018). Effectiveness of POGIL with SSI Context on Vocational High School Students’ Chemistry Learning Motivation. *Jurnal Pendidikan IPA Indonesia*, *7*(1), 85-95. https://doi.org/10.15294/jpii.v7i1.9928

Zaenal, R. M., & Hermawan, H. (2022). Efektivitas Model Pembelajaran Process Oriented Guided Inquiry Learning (POGIL) terhadap Kemampuan Pemecahan Masalah Matematik pada Siswa yang Memiliki Kemampuan Awal Matematika (KAM) Tinggi dan Rendah. *Social, Humanities, and Educational Studies (SHEs): Conference Series*, *5*(2), 198-203. https://doi.org/10.20961/shes.v5i2.58334

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